SECTION 4 - TREATMENT ALTERNATIVES AND COST MODELS

4.0 INTRODUCTION

This section gives a detailed discussion of the potential alternatives for arsenic removal in small water systems and the associated costs. The feasible options that were considered were iron-modified activated alumina (Fe-AA) (single vessel or two vessels in series), granular iron media such as granular ferric hydroxide (GFH) or Sorb-33 (one vessel or two vessels in series), coagulation with granular media filtration and POU devices (reverse osmosis and adsorption media). Several sub-options were developed for each treatment technology category based on water quality criteria, potential for partial stream treatment, and level of redundancy required. A discussion of these treatment alternatives and the assumptions for estimating capital and O&M costs for each alternative are presented. Based on these categories, cost models were developed with varying configuration options and media type. The applicability of these cost models to the impacted water systems in Arizona is presented in Section 5.

4.1 TREATMENT ALTERNATIVES FOR SMALL UTILITIES

Based on the discussions that the project team had with ADEQ and its stakeholders, the following alternatives were selected as the most feasible options for arsenic removal by small utilities.

4.1.1 Alternative 1 - Single Column Treatment Using Fe-AA

Adsorption to Fe-AA with pH adjustment to 6.5 is performed using one column (no redundancy). The column is operated to 8-10 ppb breakthrough before the media is replaced. Partial stream treatment is not possible; the complete well or POE flow is treated. Influent arsenic concentrations should be <15 ppb using this alternative. This treatment alternative is very economical for small systems, especially for backup or peaking wells. This alternative is sub-divided into two categories as shown below:

- 1a - Direct pumping into the system under pressure without a storage tank at the POE site (adsorption media design criteria - 15 ppb influent and 5 ppb average effluent arsenic levels)

- 1b - Pumping into an existing on-site storage tank for subsequent repumping into the system (adsorption media design criteria - 15 ppb influent and 5 ppb average effluent arsenic levels). A lower pressure rating is used for this treatment system.

4.1.2 Alternative 2 - Single Column Treatment Using Granular Iron Media

Adsorption to granular iron-based media (GFH or Sorb 33) is performed without pH adjustment using one column (no redundancy). The column is operated to 8-10 ppb breakthrough before the media is replaced. Partial stream treatment is not possible; the complete well or POE flow is treated. Influent arsenic concentrations should be <15 ppb to consider this alternative. Depending on economics and water quality issues, this alternative may also be performed with pH adjustment, though the granular iron media treatment option may be more economical if pH adjustment is not performed. This alternative is sub-divided into the following two categories:

- 2a - Direct pumping into the system under pressure without a storage tank at the POE site (adsorption media design criteria - 15 ppb influent and 5 ppb average effluent arsenic levels)

- 2b - Pumping into an existing on-site storage tank for subsequent repumping into the system (adsorption media criteria - 15 ppb influent and 5 ppb average effluent arsenic levels). A lower pressure rating is used for this treatment system.

4.1.3 Alternative 3 - Two Column Series Treatment Using Fe-AA

Adsorption to Fe-AA is performed using two columns in series with pH adjustment (full redundancy). Each column is operated to greater than 10 ppb breakthrough before media replacement. Greater adsorption capacity of the media is utilized due to the series arrangement and partial stream treatment is possible. This alternative is recommended for systems where a well is the primary source of water and extended outages cannot be tolerated. This alternative is sub-divided into the following five categories:

- 3a - For wells with >20 ppb arsenic, the full flow is treated as the well directly pumps into the system under pressure without storage at the POE site (adsorption media design criteria - 25 ppb influent and 10 ppb average effluent arsenic levels).

- 3b - For wells with >20 ppb arsenic, the full flow is treated as the well pumps into an existing on-site storage tank for subsequent repumping into the system (adsorption media design criteria - 25 ppb influent and 10 ppb average effluent arsenic levels).

- 3c - Partial stream treatment, where feasible (As <20 ppb), for wells pumping into an existing on-site storage tank for subsequent repumping into the system (adsorption media design criteria - 15 ppb influent and 5 ppb average effluent arsenic levels).

- 3d - Partial stream treatment, where feasible (As <20 ppb), for wells pumping into a new on-site storage tank for subsequent repumping into the system using new booster pumps (adsorption media design criteria - 15 ppb influent and 5 ppb average effluent arsenic levels).

C 3e - (Potential Option - Not Recommended) Partial stream treatment, where feasible (As <20 ppb), direct pumping into the system under pressure without storage at the POE site (very risky and control intensive).

4.1.4 Alternative 4 - Two Column Series Treatment Using Granular Iron Media

Adsorption to granular iron-based media (GFH or Sorb 33) is performed without pH adjustment using two columns in series. Each column is operated to greater than 10 ppb breakthrough before media replacement. Greater adsorption capacity is utilized due to the series arrangement and partial stream treatment is possible. This alternative is recommended for systems where a well is the primary source of water and extended outages cannot be tolerated. This alternative is sub-divided into the following five categories:

C 4a - For wells with >20 ppb arsenic, the full flow is treated as the well directly pumps into the system under pressure without storage at the POE site (adsorption media design criteria - 25 ppb influent and 10 ppb average effluent arsenic levels).

C 4b -For wells with >20 ppb arsenic, the full flow is treated as the well pumps into an existing on-site storage tank for subsequent repumping into the system (adsorption media design criteria - 25 ppb influent and 10 ppb average effluent arsenic levels).

C 4c - Partial stream treatment, where feasible (As <20 ppb), for wells pumping into an existing on-site storage tank for subsequent repumping into the system (adsorption media design criteria - 15 ppb influent and 5 ppb average effluent arsenic levels).

C 4d - Partial stream treatment, where feasible (As <20 ppb), for wells pumping into a new on-site storage tank for subsequent repumping into the system using new booster pumps (adsorption media design criteria - 15 ppb influent and 5 ppb average effluent arsenic levels).

C 4e - (Potential Option - Not Recommended) Partial stream treatment, where feasible (As <20 ppb), direct pumping into the system under pressure without storage at the POE site (very risky and control intensive).

4.1.5 Alternative 5 - Coagulation with Granular Media Filtration

Coagulation, with granular media filtration (CF) is recommended for larger treatment plants (>1 MGD), particularly those with higher levels of arsenic (>20 ppb) and which also have a higher degree of operator expertise. Significant cost savings can be expected as media replacement is not required. Approximately 5 mg/L ferric chloride would be added to form a floc and precipitate the arsenic. Partial stream treatment is generally not feasible. Spent backwash is settled and thickened solids are disposed off-site. Recovered water from backwash settling is treated through the WTP. This alternative is sub-divided into the following two categories:

- 5a - Direct pumping into the system under pressure without a storage tank at the POE site.
- 5b - Pumping into an existing on-site storage tank for subsequent repumping into the system. A lower pressure rating is used for this treatment system.

4.1.6 Alternative 6 - Point-of-Use Devices

In areas where centralized treatment is not feasible, POU or under-the-sink treatment may be a cost-effective alternative, especially for systems serving fewer than 100 connections and an average population of less than 300. POU treatment consists of single-tap treatment, where the kitchen tap in a household is connected to a treatment device and the treated water is used only for cooking and drinking. Significantly less water is treated with single-tap treatment (about 2% of a system's total flow), thereby reducing the overall cost for the user. POU treatment offers ease of installation, treats only water used for human consumption, has lower initial capital costs and reduces engineering costs associated with construction of a full-scale treatment plant. The feasible POU treatment alternatives are listed below:

- 6a - POU treatment using adsorption (Mn-AA or iron media)
- 6b - POU treatment using reverse osmosis (RO)

4.2 TREATMENT COST ASSUMPTIONS

Cost equations to estimate the capital and operations and maintenance (O&M) costs for all the alternatives listed above were developed for flow capacities ranging from 0.03 MGD to 2 MGD for adsorption systems, and 1 MGD to 5 MGD for CF systems. These cost equations considered the following aspects of a treatment facility:

- Pre and post-treatment (e.g., cartridge filtration or pH adjustment)
- Partial stream treatment and blending back prior to POE
- Solid and liquid residuals handling
- Impact of influent and treated water quality
- Piloting, permitting, installation and training
- Engineering, design and construction management
- Compliance monitoring and record keeping
- Labor for operations and maintenance
- Building and land
- Energy
- Additional pumping and storage

4.2.1 Adsorption Media (Fe-AA and Iron Media) Cost Assumptions

Table 4.1 shows some of the assumptions that were used to estimate the pressure vessel size, media volume required, and costs for Fe-AA and granular iron media treatment.

4.2.1.1 Media Replacement

Adsorption media is replaced based on media exhaustion, i.e., bed volumes treated. The bed volumes for media exhaustion were estimated using pilot and full-scale demonstration data from various arsenic treatment studies that were completed in Arizona and other regions, as discussed in Section 4.4. The bed volumes for media exhaustion were correlated to pH (ambient or adjusted target) and the presence of co-occurring ions such as silica, fluoride and phosphate.

4.2.1.2 Single Column Treatment

For facilities with single adsorption column, costs were developed assuming treatment of complete flow, with no split-stream treatment. It is assumed that the system has one day's storage of a redundant well under this alternative. The one-day storage ensures a continuous supply of treated potable water when the adsorption vessel is taken off-line for maintenance (e.g., media replacement). Media replacement for single column systems will be performed at 8-10 ppb breakthrough.

4.2.1.3 Two Column Treatment

For facilities with treatment with two columns in series, costs were developed for both partial stream treatment (<20 ppb arsenic) and full stream treatment (>20 ppb arsenic). In two-column systems, water will be passed serially through both columns that are filled with the adsorption media.

For partial stream treatment, the roughing (first) column is operated until a breakthrough of 10-13 ppb; the average arsenic effluent concentration is 5-6 ppb throughout the column run. The media in the roughing column is then replaced. All the water that needs to be treated is passed through the polishing (second) column when the media is being replaced in the roughing column. After media replacement, the polishing column will be the roughing column and vice versa.

For full stream treatment, the roughing column is operated until a breakthrough of 15-20 ppb, the average arsenic effluent concentration is 10 ppb throughout the column run. The media in the roughing column is then replaced. All the water that needs to be treated is passed through the polishing (second) column when the media is being replaced in the roughing column. After media replacement, the polishing column will be the roughing column and vice versa. The new polishing column is operated until 8-10 ppb breakthrough, at which time it is switched to operate as a roughing column.

Table 4.1: Summary of Fe-AA and Granular Iron Media Design Parameters

Design Parameter/ Operating Condition	**Fe-AA**	**Granular Iron Media**
EBCT (per vessel)	5 minutes	2.5 minutes
Operating pH	6.5	8.0
Target Hydraulic Loading Rate	5-7 gpm/ft^2	6-8 gpm/ft^2
Vessel type	Carbon steel/epoxy coated (> 3 ft diameter) or fiberglass (#3 ft diameter)	Carbon steel/epoxy coated (> 3 ft diameter) or fiberglass (#3 ft diamter)
Pipe type	DIP	DIP
Enclosure	Masonry building	Masonry building
Backwash Basin	Steel tank	Steel tank
Operating pressure	30 - 100 psi (depending on configuration)	30 - 100 psi (depending on configuration)
Media Bulk Density	47 lbs/ft^3	72 lbs/ft^3 (GFH) 30 lbs/ft^3 (Sorb-33)
Minimum Bed Depth	3 feet	2 feet
Maximum Bed Depth	4 feet	3 feet
Maximum Vessel Diameter	14 feet	12 feet
Media Expansion + Freeboard	1.5 times the media depth + 1.5 feet for support sand and/or internals	1.5 times the media depth + 1.5 feet for support sand and/or internals
Water quality parameters interference	Silica, pH, fluoride, sulfate, TDS, iron, manganese	Silica, pH, phosphorus, sulfate, iron, manganese
Bed Volumes Before Breakthrough	Variable based on operating pH and raw water quality. Existing pilot studies used to estimate media life.	Variable based on operating pH and raw water quality. Existing pilot studies used to estimate media life.

4.2.1.4 Capital Costs

The size of the one or two column Fe-AA or iron media system was developed using the design criteria listed in Table 4.1. Vendor quotations were obtained for significant capital cost items such as pressure vessels, pumps, metering pumps, tanks and media, sitework, electrical, instrumentation, and yard piping costs. The calculated process cost was incremented by the following percentages to account for the costs of ancillary facilities.

- 15% for site work
- 20% for installation
- 20% for contingencies and mobilization
- 10% for piping allowance
- 15% for instrumentation and control (I&C) allowance
- 15% for electrical allowance
- 8.5% for taxes and bonding
- 20-30% for engineering design - varies by WTP size (optional and not included in base costs, can be added by users of web based tool)
- 10-15% for legal and administrative fees (optional and not included in base costs, can be added by users of web based tool)

The following assumptions were made when calculating the treatment process costs:

- Additional costs for variable frequency drive pumps (alternatives 3c and 4c).
- 10% reduction in vessel costs for lower pressure rated vessels (alternatives 1b, 2b, 3b, 3c, 3d, 4b, 4c and 4d).
- Costs for chemicals storage (sulfuric acid and caustic soda) are based on a 30 day storage at 30% usage rate (where pH adjustment is required).

4.2.1.5 Operation and Maintenance (O&M) Costs

The treatment O&M costs were developed based on the following assumptions:

- Power cost of $0.08 per kWh
- Labor cost of $40 per hour for an operator and $50 per hour for a supervisor
- Media replacement service cost of $1,500-$3,000, depending on the system size
- Media costs for Fe-AA and iron media at $0.90 per lb and $2.50 per lb (GFH), respectively
- Residuals disposal cost of $120 per ton
- Sulfuric acid cost of $120 per ton ($0.06 per pound)
- Caustic soda cost of $375 per ton ($0.19 per pound) and
- Arsenic analysis cost of $15 per sample

4.2.2 Coagulation with Granular Media Filtration Cost Assumptions

Costs for CF process were developed based on the following assumptions:

- A coagulant dose of 5 mg/L, sufficient to treat up to 50 ppb influent arsenic
- $FeCl_3$ at 30% solution concentration and $0.19 per pound
- Maximum operating pH of 8.0
- "G" value of 1000 sec^{-1} to provide mixing energy.
- 30" deep anthracite filters with a loading rate of 6 gpm/ft^3
- 5% thickened solids residuals
- One additional filter provided for firm capacity during backwashing

4.2.2.1 Capital Costs

Similar to the adsorption media cost, quotes were obtained from vendors for significant capital cost items such as pressure vessels, pumps, metering pumps, tanks and pressure filtration units, sitework, electrical, instrumentation, and yard piping costs. The calculated process cost was incremented by the following percentages to account for construction and engineering costs of ancillary facilities:

- 15% for site work
- 20% for installation
- 20% for contingencies and mobilization
- 20% for piping allowance
- 15% for instrumentation and control (I&C) allowance
- 15% for electrical allowance
- 8.5% for taxes and bonding
- 20-30% for engineering design - varies by WTP size (optional and not included in base costs, can be added by users of web based tool)
- 10-15% for legal and administrative fees (optional and not included in base costs, can be added by users of web based tool)

4.2.2.2 O&M Costs

The O&M costs were developed assuming:

- Power cost of $0.08 per kWh
- Labor cost of $40 per hour for an operator and $50 per hour for a supervisor
- Thickened sludge disposal off-site (non-hazardous waste) of $0.20 per pound
- Ferric chloride cost of $400 per ton ($0.19 per pound)
- Arsenic analysis cost of $15 per sample

4.2.3 POU Adsorption and POU RO Cost Assumptions

Capital costs and operational and maintenance costs for POU adsorption and POU RO units were determined based on the following assumptions:

- Average household - 3 individuals; 1 gallon per day per person, approximately 1000 gallons per year consumption.
- Annual treatment is 1,000 gallons.
- Installation costs for POU-RO and POU adsorption units - $150.
- Equipment cost/media cost:
  Reverse osmosis - $350.
  Adsorption units - $150.
- Operator labor charges (per hour) per household - $25 (small system operations).
- Managerial charges (per hour) per household - $50.
- Cost of analysis (per sample) - $12.
- Media replacement cost:
  Reverse osmosis - $95.
  Adsorption units - $70.

Costs for POU adsorption and POU RO were developed assuming that the POU systems will be leased from a NSF certified supplier on a contract basis. The leasing arrangement includes costs for servicing and replacement of adsorption media cartridge or RO membrane element. The POU system costs also includes costs for monitoring to stay in compliance with the Federal and State guidelines.

The POU adsorption system was assumed to consist of one adsorption cartridge that can treat approximately 1,000 gallons of water before it has to be replaced. The POU RO system was assumed to be a 3-stage system that included a pre-filter (for particulate removal), RO membrane and a post filter (for taste enhancement). Quotes from several vendors were obtained for leasing and maintenance of POU systems.

4.3 EXISTING PILOT TESTING DATA

Pilot and full scale data from various arsenic treatment studies that were performed in Arizona and other regions was used to determine the bed volumes (BVs) treated to breakthrough. The BVs for media exhaustion were correlated to operating pH and the presence of co-occurring ions such as silica, fluoride and phosphorus. The number of days of operation of the adsorption column before media replacement can be determined from the BVs to breakthrough. A summary of the existing pilot data is presented in Table 4.2. The water quality profiles, operating restrictions and BVs treated to breakthrough are also included. The applicability of the pilot test data in the Master Plan is indicated by (Y/N) in Table 4.2.

The adsorption capacity of the Fe-AA and granular iron media was estimated to be 0.0003 lb arsenic/lb media and 0.0004 lb arsenic/lb media respectively, based on the data from Table 4.2. pH, silica, fluoride, phosphorus, iron and manganese were considered as interfering parameters. Due to limited pilot scale data on phosphorus, iron and manganese, these parameters were not used in the determination of adsorption capacity of the media. The operating pH was 6.5 for Fe-AA and 8.0 (maximum) for iron media. No significant interferences were observed. The adsorption capacity of the media will be adjusted for each impacted system in Arizona (based on influent arsenic levels) when determining the media replacement costs.

Table 4.2: Existing Pilot Testing Data Summary

				Influent			Influent				
Location	Media Type	Flowrate (gpm)	EBCT (min)	Arsenic (mg/L)	pH Std. Units	Operating pH	Fluoride (mg/L)	Silica (mg/L)	Bed Volumes Treated to 0.010 mg/L	Adsorption Capacity lb As/lb media	Operating Restrictions
Well 280: Phoenix, AZ	Fe-AA [1]	3	5	0.014	7.7	6.7	0.47	48	18,500	0.00023	pH adjustment
Well 280: Phoenix, AZ	GFH	6	2.5	0.014	7.7	7.5	0.47	48	42,100	0.00052	
Well 290: Phoenix, AZ	GFH	6.5	2.5	0.0089	7.9	7.5	0.45	38	92,400	0.00050	
Well 290: Phoenix, AZ	GFH	6.5	2.5	0.0089	7.9	7.9	0.45	38	89,000	0.00048	
Well 233: Phoenix, AZ	GFH	6.5	2.5	0.0093	8.1	7.5	0.41	32	104,000	0.00062	
Well 233: Phoenix, AZ	GFH	6.5	2.5	0.0093	8.1	8.1	0.41	32	88,000	0.00052	
Sun City West, AZ	Fe-AA	3	5	0.023	8.3	8.3	1.8	13	4,200	0.00010	
Sun City West, AZ	GFH	6	2.5	0.023	8.3	8.3	1.8	13	17,250	0.00043	
Metro Water, Tucson, AZ	Fe-AA	3	5	0.011	6.9	6.9	1.5	42	26,000	0.00022	Silica interference
Metro Water, Tucson, AZ	GFH	3	2.5	0.011	6.9	6.9	1.5	42	>45,000	0.00037	Silica interference
Carson City, NV	GFH	0.4	1.7	0.015	8.3	8.3	1.4	17	20,000	0.00028	
Stagecoach, NV	Fe-AA [2]	3	5	0.023	8.2	8.2	0.13	36	2,300	0.00006	Silica interference
Stagecoach, NV	GFH [2]	6	2.5	0.023	8.2	8.2	0.13	36	<7,300	0.00018	Silica interference

1.) Influent pH adjusted to 6.7 with sulfuric addition.
2.) Variable influent iron decreased adsorption capacity, capacity was recovered after backwash.

4.4 DEVELOPMENT OF COST MODELS

Based on the assumptions mentioned in the previous subsections, cost equations for each alternative were developed. Unit quantity takeoffs were used to develop the capital costs and annual O&M costs for systems with design flow capacities in the range of 0.03-2 MGD for adsorption systems and 1-5 MGD for CF systems. The design criteria, capital costs and O&M costs for each alternative are summarized in this section.

4.4.1 Alternatives 1a and 1b Cost Models

4.4.1.1 System Design Criteria

The schematics for Alternatives 1a and 1b are shown in Figures 4.1 and 4.2, respectively. The design flow through the treatment unit will be 21-1389 gpm and one 5 minute Empty Bed Contact Time (EBCT) contactor is recommended as the treatment vessel configuration. The Fe-AA column was assumed to operate 100% of the time in computing O&M costs. The vessel diameter was calculated to be 2-12 ft, based on the system flow. The media depth in the column is 4 ft. The pressure drop through the system is a maximum of 10 psi. The average operating pressure is 100 psi for Alternative 1a and 30 psi for Alternative 1b. For small systems, a manually operated cartridge filter is used. Acid and caustic facilities are required for pH adjustment to 6.5 and readjustment after treatment. Under these operating conditions, the Fe-AA column is expected to last a period of 78 days before breakthrough for a raw water with 15 ppb influent arsenic and no significant interferences. After the column breaks through, the media is replaced. The adsorption media is to be backwashed monthly and the backwash volume is approximately 8 BVs. A steel tank is used for backwash recovery. For large systems, the spent media is stored on-site in a holding area and disposed to a municipal landfill as it is not considered hazardous. Approximately 67-4,511 cubic feet of media (3,000-203,000 lbs) will have to be disposed of every year, based on the system capacity. No spent media handling facilities are provided for treatment plants <0.5 MGD (tanker facilities provided by media vendor during changeout). The system design criteria for single column Fe-AA treatment is shown in Table 4.3.

Table 4.3: Design Criteria for Single Column Fe-AA Treatment (1a and 1b)

Parameter	Units	Value
Flow	gpm	21-1389
Average Influent Arsenic level	ppb	15
No. of Treatment Vessels		1
EBCT (each vessel)	min	5
Vessel Diameter	ft	2-12
Media Depth	ft	4
Vessel Height (side shell)	ft	7.5
Operating Pressure	psi	100 (Alternative 1a) 30 (Alternative 1b)
Maximum Headloss	psi	10
Operating pH	std. units	6.5
Operating time until arsenic breakthrough[1]	days	78
Acid/Caustic facilities required?		Yes[2]
Backwash Equalization Basin	BVs	8
Spent Media Disposal		Landfill
Backwash Frequency		Monthly
Clearwell Detention Time (Alternative 1b)	min	10

[1]Media replacement interval for continuous operation

[2]pH adjustment necessary for Fe-AA based on pilot testing data

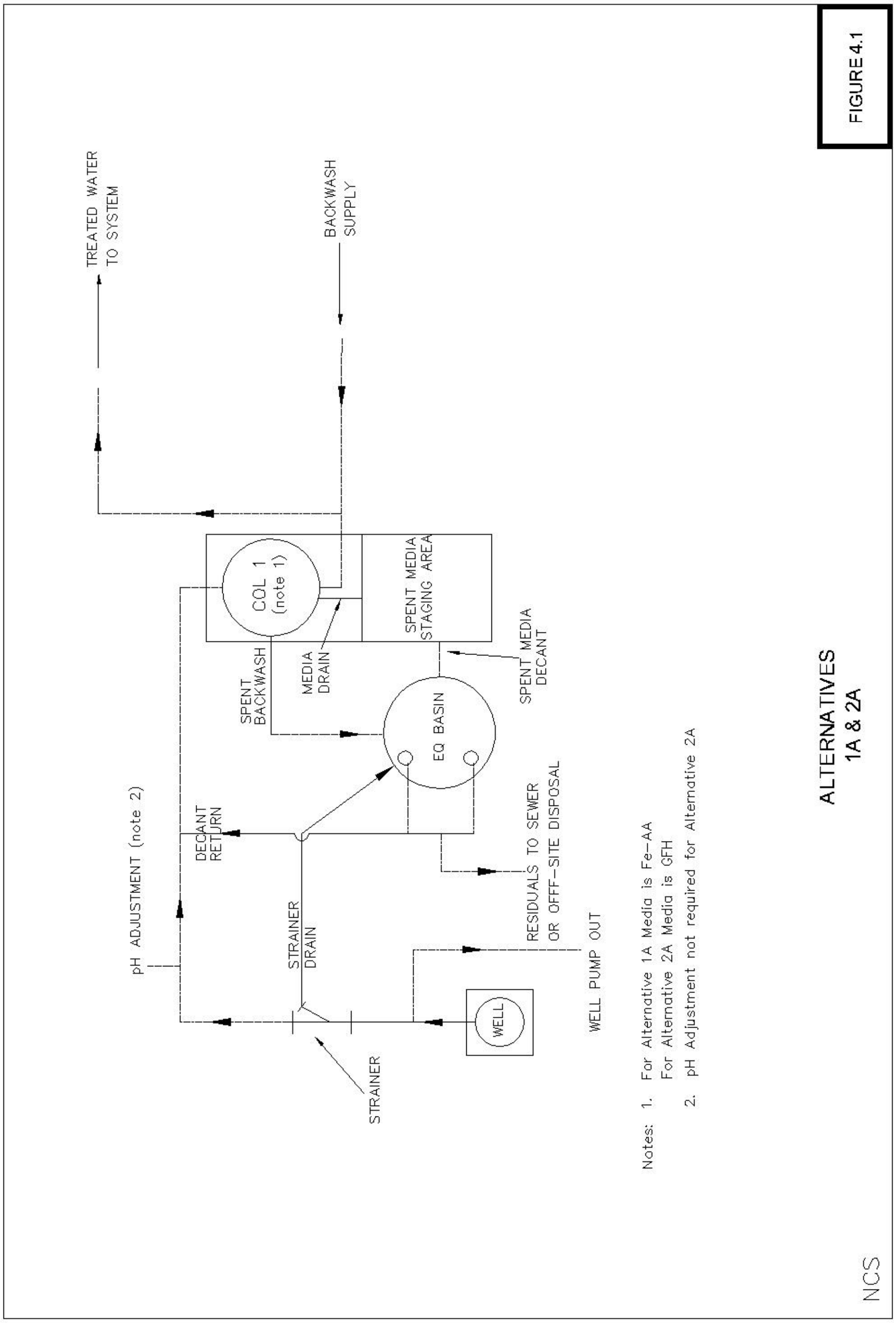
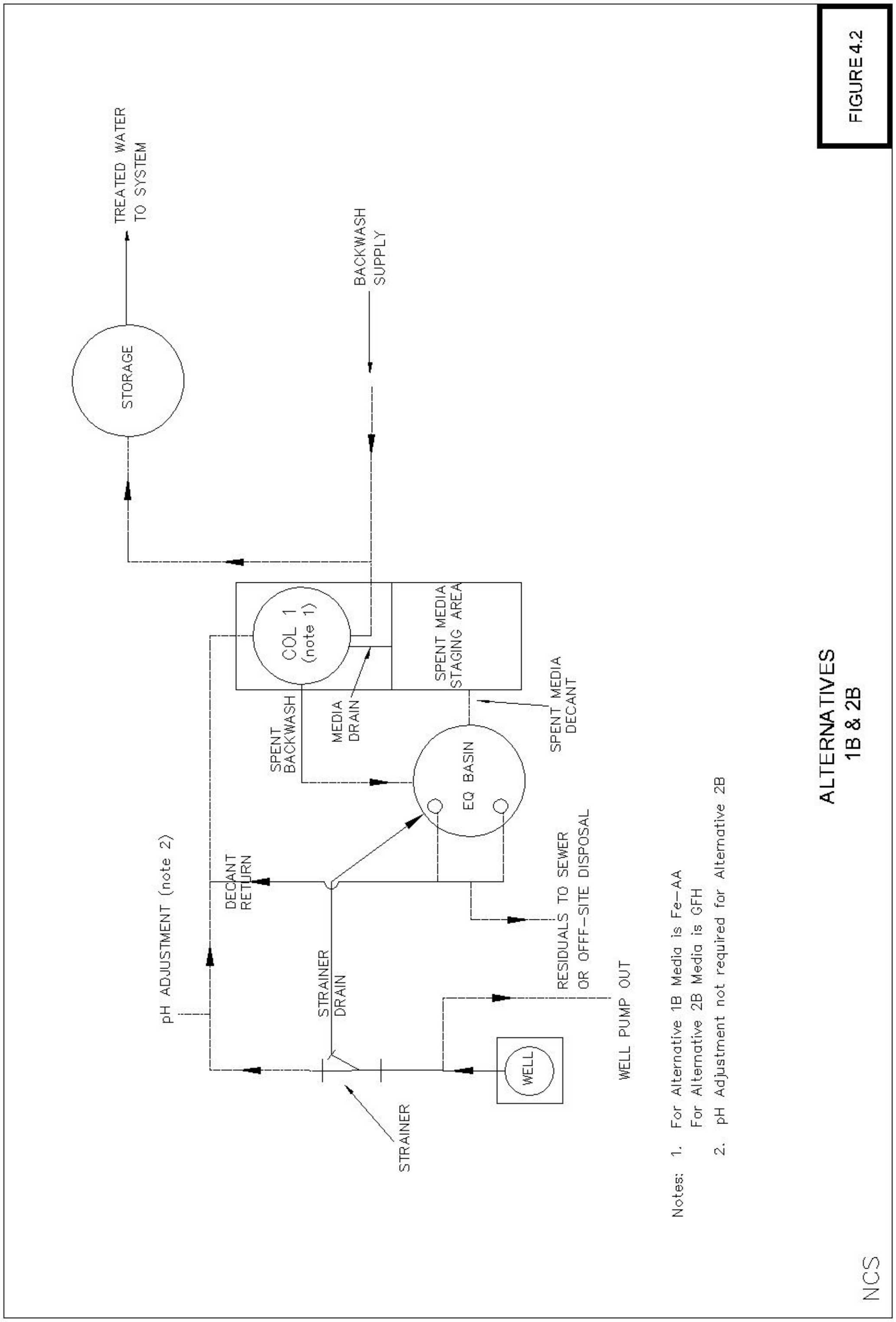


FIGURE 4.1
TREATED WATER
TO SYSTEM
BACKWASH
SUPPLY
COL 1
(note 1)
SPENT MEDIA
STAGING AREA
SPENT
BACKWASH
MEDIA
DRAIN
SPENT MEDIA
DECANT
EQ BASIN
pH ADJUSTMENT (note 2)
DECANT
RETURN
RESIDUALS TO SEWER
OR OFFF-SITE DISPOSAL
STRAINER
DRAIN
WELL PUMP OUT
WELL
STRAINER
Notes: 1. For Alternative 1A Media is Fe-AA
For Alternative 2A Media is GFH
2. pH Adjustment not required for Alternative 2A
ALTERNATIVES
1A & 2A
NCS


TREATED WATER
TO SYSTEM
STORAGE
BACKWASH
SUPPLY
COL 1
(note 1)
SPENT MEDIA
STAGING AREA
SPENT
BACKWASH
MEDIA
DRAIN
SPENT MEDIA
DECANT
EQ BASIN
pH ADJUSTMENT (note 2)
DECANT
RETURN
STRAINER
DRAIN
RESIDUALS TO SEWER
OR OFFF-SITE DISPOSAL
WELL PUMP OUT
WELL
STRAINER
Notes: 1. For Alternative 1B Media is Fe-AA
For Alternative 2B Media is GFH
2. pH Adjustment not required for Alternative 2B
ALTERNATIVES
1B & 2B
NCS
FIGURE 4.2

4.4.1.2 Cost Evaluation

A summary of estimated capital costs and annual O&M costs for Alternative 1a are shown in Tables 4.4 and 4.5, respectively. A summary of estimated capital costs and annual O&M costs for Alternative 1b are shown in Tables 4.6 and 4.7, respectively. These estimated costs were plotted as a function of system design flow to develop capital and O&M cost curves to estimate costs for systems of various capacities throughout Arizona. The capital and O&M cost curves for Alternative 1a are as shown in Figures 4.3 and 4.4, respectively. The capital and O&M cost curves for Alternative 1b are as shown in Figures 4.5 and 4.6, respectively.

Table 4.4: Estimated Capital Costs for Alternative 1a (Single Column Treatment with Fe-AA - direct pumping into system)

	Capacity in MGD					
Fe-AA System Facilities Costs	0.03	0.1	0.2	0.5	1.0	2.0
Booster Pumping/ Straining	$7,500	$7,500	$8,550	$18,000	$28,000	$32,000
Residuals Handling Facilities	$3,267	$8,956	$13,711	$39,149	$63,778	$71,398
Fe-AA System Facilities	$24,707	$44,356	$52,713	$115,281	$161,563	$323,126
Chemical Feed Faciliites	$10,854	$17,979	$33,358	$66,495	$122,590	$237,380
Building	$32,000	$32,000	$32,000	$38,400	$51,840	$108,000
Piping, I&C, Electrical, Yard Piping Allowances	$18,531	$31,516	$43,333	$95,570	$150,372	$265,561
Total Facility Cost, $	$96,858	$142,307	$183,664	$372,895	$578,143	$1,037,465
Contingency, 20%	$19,372	$28,461	$36,733	$74,579	$115,629	$207,493
Taxes & Bonding, 8.5%	$9,880	$14,515	$18,734	$38,035	$58,971	$105,821
Total Estimated Fe-AA Facility Cost	$126,109	$185,284	$239,131	$485,510	$752,742	$1,350,779

Table 4.5: Annual O&M Costs for Alternative 1a (Single Column Treatment with Fe-AA - direct pumping into system)

	Capacity in MGD					
Facility assumed to operate 100% of time	0.03	0.1	0.2	0.5	1.0	2.0
Annual Power Cost, $/yr	$539	$1,617	$2,694	$2,828	$5,637	$8,446
H2SO4 Cost, $/yr	$137	$457	$913	$2,283	$4,566	$9,132
NaOH Cost, $/yr	$310	$1,035	$2,070	$5,175	$10,350	$20,700
Annual Media Replacement Costs, $/yr	$2,740	$9,132	$18,265	$45,662	$91,323	$182,646
Media Replacement Service Cost, $	$2,500	$2,500	$5,000	$8,000	$10,000	$15,000
Waste Media Disposal Costs, $/yr	$201	$670	$1,339	$3,349	$6,697	$13,394
Total Estimated Labor Costs, $/yr	$2,059	$2,059	$4,493	$8,299	$8,299	$8,299
Equipment Maintenance Costs, $/yr	$1,261	$1,853	$2,391	$4,855	$7,527	$13,508
Arsenic Analysis cost, $/yr	$90	$90	$90	$90	$90	$90
Total Estimated Annual O&M Costs, $/yr	$7,337	$16,912	$32,256	$72,541	$134,490	$256,216
Unit Annual O&M Costs, $/1000 gal	$0.67	$0.46	$0.44	$0.40	$0.37	$0.35

Table 4.6: Estimated Capital Costs for Alternative 1b (Single Column Treatment with Fe-AA - pumping into existing on-site storage tank and repumping into system)

	Capacity in MGD					
Fe-AA System Facilities Costs	0.03	0.1	0.2	0.5	1.0	2.0
Booster Pumping/ Straining	$7,500	$7,500	$8,550	$18,000	$28,000	$32,000
Residuals Handling Facilities	$3,267	$8,956	$13,711	$39,149	$63,778	$71,398
Fe-AA System Facilities	$22,307	$40,156	$47,913	$104,931	$147,763	$295,526
Chemical Feed Faciliites	$10,854	$17,979	$33,358	$66,495	$122,590	$237,380
Building	$32,000	$32,000	$32,000	$38,400	$51,840	$108,000
Piping, I&C, Electrical, Yard Piping Allowances	$17,571	$29,836	$41,413	$91,430	$144,852	$254,521
Total Facility Cost, $	$93,498	$136,427	$176,944	$358,405	$558,823	$998,825
Contingency, 20%	$18,700	$27,285	$35,389	$71,681	$111,765	$199,765
Taxes & Bonding, 8.5%	$9,537	$13,916	$18,048	$36,557	$57,000	$101,880
Total Estimated Fe-AA Facility Cost	$121,735	$177,628	$230,382	$466,644	$727,587	$1,300,470

Table 4.7: Annual O&M Costs for Alternative 1b (Single Column Treatment with Fe-AA - pumping into existing on-site storage tank and repumping into system)

	Capacity in MGD					
Facility assumed to operate 100% of time	0.03	0.1	0.2	0.5	1.0	2.0
Annual Power Cost, $/yr	$539	$1,617	$2,694	$2,828	$5,637	$8,446
H2SO4 Cost, $/yr	$137	$457	$913	$2,283	$4,566	$9,132
NaOH Cost, $/yr	$310	$1,035	$2,070	$5,175	$10,350	$20,700
Annual Media Replacement Costs, $/yr	$2,740	$9,132	$18,265	$45,662	$91,323	$182,646
Media Replacement Service Cost, $	$2,500	$2,500	$5,000	$8,000	$10,000	$15,000
Waste Media Disposal Costs, $/yr	$201	$670	$1,339	$3,349	$6,697	$13,394
Total Estimated Labor Costs, $/yr	$2,059	$2,059	$4,493	$8,299	$8,299	$8,299
Equipment Maintenance Costs, $/yr	$1,217	$1,776	$2,304	$4,666	$7,276	$13,005
Arsenic Analysis cost, $/yr	$90	$90	$90	$90	$90	$90
Total Estimated Annual O&M Costs, $/yr	$7,294	$16,836	$32,168	$72,352	$134,238	$255,713
Unit Annual O&M Costs, $/1000 gal	$0.67	$0.46	$0.44	$0.40	$0.37	$0.35

Figure 4.3: Total Capital Costs for Fe-AA (Alternative 1a)

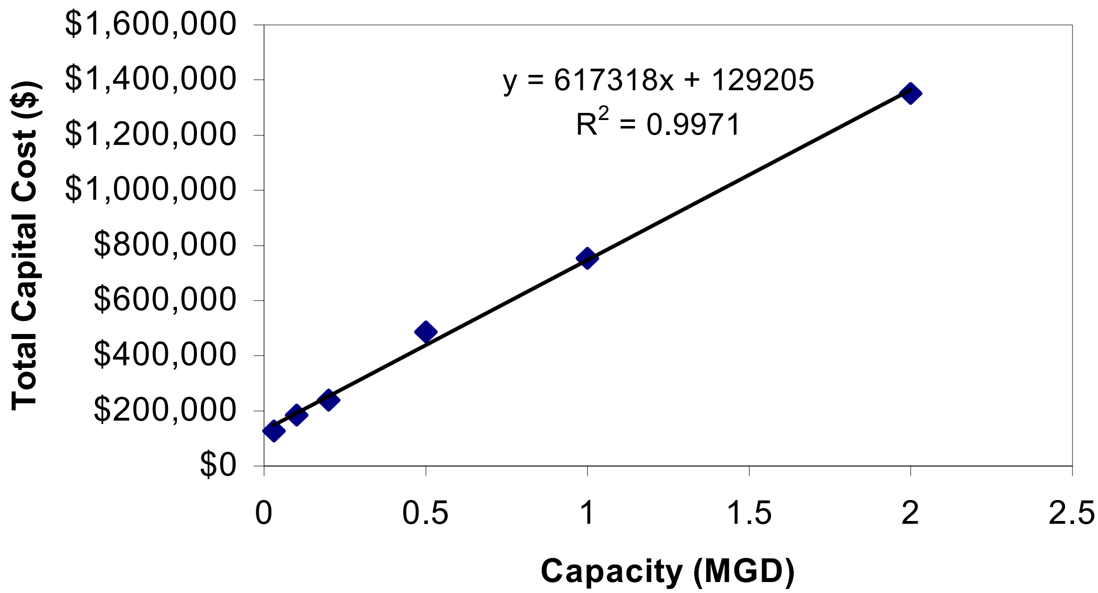


Figure 4.4: Total Annual O&M Costs for Fe-AA (Alternative 1a)

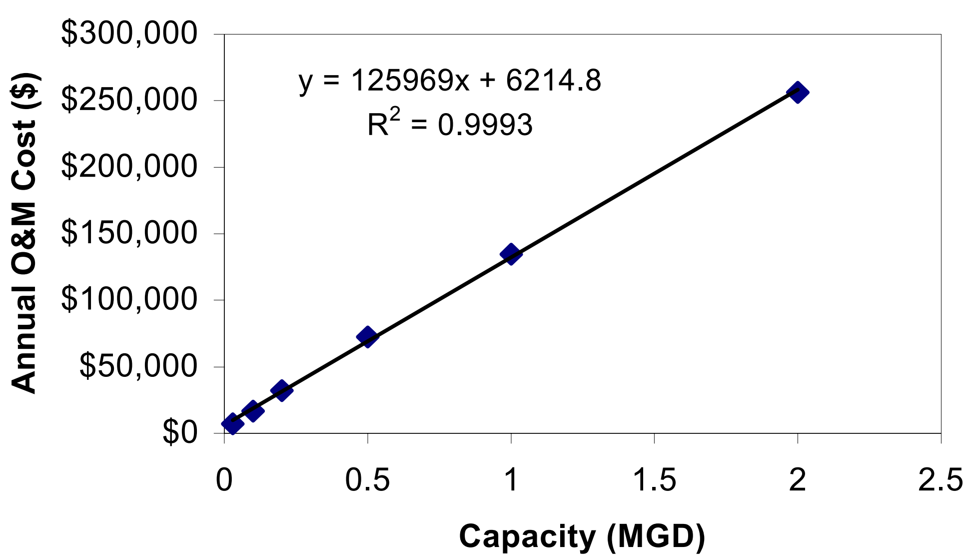


Figure 4.5: Total Capital Costs for Fe-AA (Alternative 1b)

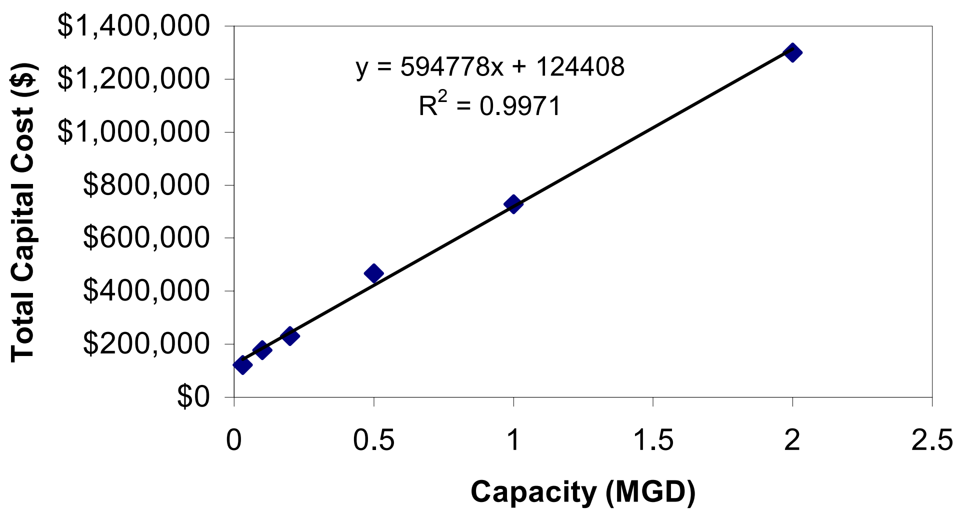
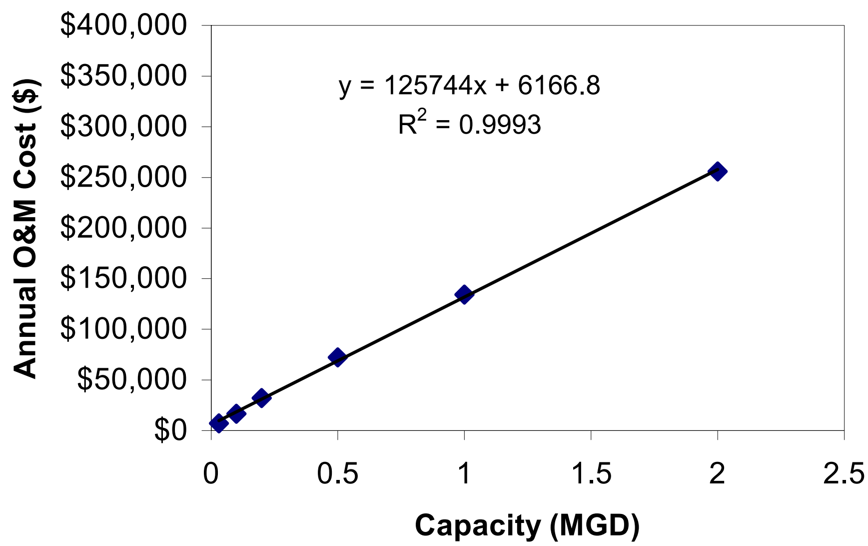


Figure 4.6: Total Annual O&M Costs for Fe-AA (Alternative 1b)



4.4.2 Alternatives 2a and 2b Cost Models

4.4.2.1 System Design Criteria

The schematics for Alternatives 2a and 2b are shown in Figures 4.1 and 4.2, respectively. The design flow through the treatment unit is 21-1389 gpm and one 2.5 minute EBCT contactor is recommended as the treatment configuration. The GFH column was assumed to operate 100% of the time in computing O&M costs. The vessel diameter was calculated to be 2-12 ft, based on the system flow. The media depth in the column is 2.7 ft. The pressure drop through the system is 10 psi. The average operating pressure is 100 psi for Alternative 2a and 30 psi for Alternative 2b. For small systems, a manually operated cartridge filter is used. No pH adjustment is required. Under these operating conditions the granular iron media column is expected to last a period of 80 days before breakthrough for a raw water with 15 ppb influent arsenic and no significant interferences. After the column breaks through, the media is replaced. The granular iron media is to be backwashed monthly and the backwash volume is approximately 13 BVs. A steel tank is used for backwash recovery. For large systems, the spent media is stored on-site in a holding area and disposed to a municipal landfill as it is not considered hazardous. A steel tank is used for backwash recovery. Approximately 50-3,400 cubic feet of media (2,250-153,000 lbs) will have to be disposed of every year, based on the system capacity. No spent media handling facilities are provided for treatment plants <0.5 MGD (tanker facilities provided by media vendor during changeout). The system design criteria for single column granular iron media treatment is shown in Table 4.8.

4.4.2.2 Cost Evaluation

A summary of estimated capital costs and annual O&M costs for Alternative 2a are shown in Tables 4.9 and 4.10, respectively. A summary of estimated capital costs and annual O&M costs for Alternative 2b are shown in Tables 4.11 and 4.12, respectively. These estimated costs were plotted as a function of system design flow to develop capital and O&M cost curves to estimate costs for systems of various capacities throughout Arizona. The capital and O&M cost curves for Alternative 2a are shown in Figures 4.7 and 4.8, respectively. The capital and O&M cost curves for Alternative 2b are shown in Figures 4.9 and 4.10, respectively.

Table 4.8: Design Criteria for Single Column Granular Iron Media Treatment (2a and 2b)

Parameter	Units	Value
Flow	gpm	21-1389
Average Influent Arsenic level	ppb	15
No. of Treatment Vessels		1
EBCT (each vessel)	min	2.5
Vessel Diameter	ft	2-12
Media Depth	ft	2.7
Vessel Height (side shell)	ft	6
Operating Pressure	psi	100 (Alternative 2a) 30 (Alternative 2b)
Maximum Headloss	psi	10
Maximum Operating pH	std. units	8.0
Operating time until arsenic breakthrough[1]	days	80
Acid/Caustic facilities required?		No[2]
Backwash Equalization Basin	BVs	13
Spent Media Disposal		Landfill
Backwash Frequency		Monthly
Clearwell detention time (Alternative 2b)	min	10

[1]Media replacement interval based on continuous operation

[2]pH adjustment is not necessary for granular iron media for waters up to pH 8.0

Table 4.9: Estimated Capital Costs for Alternative 2a (Single Column Treatment using Iron media - direct pumping into the system)

GFH System Facilities Costs	Capacity in MGD					
	0.03	0.1	0.2	0.5	1.0	2.0
Residuals Handling Facilities	$2,954	$7,914	$11,628	$36,545	$58,569	$66,189
Booster Pumping/ Straining	$7,500	$7,500	$8,550	$18,000	$28,000	$32,000
GFH System Facilities	$25,504	$35,013	$58,027	$107,867	$174,334	$348,667
Building	$32,000	$32,000	$32,000	$38,400	$51,840	$108,000
Piping, I&C, Electrical, Yard Piping Allowances	$14,175	$19,476	$29,893	$63,229	$100,889	$175,271
Total Facility Cost, $	$81,612	$100,168	$136,625	$259,700	$404,952	$721,447
Contingency, 20%	$16,322	$20,034	$27,325	$51,940	$80,990	$144,289
Taxes & Bonding, 8.5%	$8,324	$10,217	$13,936	$26,489	$41,305	$73,588
Total Estimated GFH Facility Cost	$107,209	$133,583	$184,215	$346,041	$543,070	$955,147

Table 4.10: Annual O&M Costs for Alternative 2a (Single Column Treatment using Iron media - direct pumping into the system)

Facility assumed to operate 100% of time	Capacity in MGD					
	0.03	0.1	0.2	0.5	1.0	2.0
Annual Power Cost, $/yr	$539	$1,617	$2,694	$2,826	$5,635	$8,444
Annual Media Replacement Costs, $/yr	$4,566	$15,221	$30,441	$76,103	$152,205	$304,410
Media Replacement Service Cost, $	$2,500	$2,500	$5,000	$8,000	$10,000	$15,000
Waste Media Disposal Costs, $/yr	$120	$402	$540	$2,009	$4,018	$8,036
Total Estimated Labor Costs, $/yr	$2,059	$2,059	$4,493	$8,299	$8,299	$8,299
Equipment Maintenance Costs, $/yr	$1,072	$1,336	$1,842	$3,460	$5,431	$9,551
Arsenic Analysis cost, $/yr	$60	$60	$60	$60	$60	$60
Total Estimated Annual O&M Costs, $/yr	$10,916	$23,194	$45,070	$100,757	$185,648	$353,801
Unit Annual O&M Costs, $/1000 gal	$1.00	$0.64	$0.62	$0.55	$0.51	$0.48

Table 4.11: Estimated Capital Costs for Alternative 2b (Single Column Treatment with Iron media - pumping into existing on-site storage tank and repumping into system)

GFH System Facilities Costs	Capacity in MGD					
	0.03	0.1	0.2	0.5	1.0	2.0
Residuals Handling Facilities	$2,954	$7,914	$11,628	$36,545	$58,569	$66,189
Booster Pumping/ Straining	$7,500	$7,500	$8,550	$18,000	$28,000	$32,000
GFH System Facilities	$23,104	$32,013	$53,227	$99,587	$161,914	$323,827
Building	$32,000	$32,000	$32,000	$38,400	$51,840	$108,000
Piping, I&C, Electrical, Yard Piping Allowances	$13,423	$18,971	$29,362	$61,653	$99,393	$168,807
Total Facility Cost, $	$78,981	$98,398	$134,766	$254,184	$399,716	$698,824
Contingency, 20%	$15,796	$19,680	$26,953	$50,837	$79,943	$139,765
Taxes & Bonding, 8.5%	$8,056	$10,037	$13,746	$25,927	$40,771	$71,280
Total Estimated GFH Facility Cost	$102,834	$128,114	$175,466	$330,948	$520,431	$909,868

Table 4.12: Annual O&M Costs for Alternative 2b (Single Column Treatment with Iron media - pumping into existing on-site storage tank and repumping into system)

Facility assumed to operate 100% of time	Capacity in MGD					
	0.03	0.1	0.2	0.5	1.0	2.0
Annual Power Cost, $/yr	$539	$1,617	$2,694	$2,826	$5,635	$8,444
Annual Media Replacement Costs, $/yr	$4,566	$15,221	$30,441	$76,103	$152,205	$304,410
Media Replacement Service Cost, $	$2,500	$2,500	$5,000	$8,000	$10,000	$15,000
Waste Media Disposal Costs, $/yr	$120	$402	$540	$2,009	$4,018	$8,036
Total Estimated Labor Costs, $/yr	$2,059	$2,059	$4,493	$8,299	$8,299	$8,299
Equipment Maintenance Costs, $/yr	$1,028	$1,281	$1,755	$3,309	$5,204	$9,099
Arsenic Analysis cost, $/yr	$60	$60	$60	$60	$60	$60
Total Estimated Annual O&M Costs, $/yr	$10,873	$23,139	$44,983	$100,606	$185,422	$353,348
Unit Annual O&M Costs, $/1000 gal	$0.99	$0.63	$0.62	$0.55	$0.51	$0.48

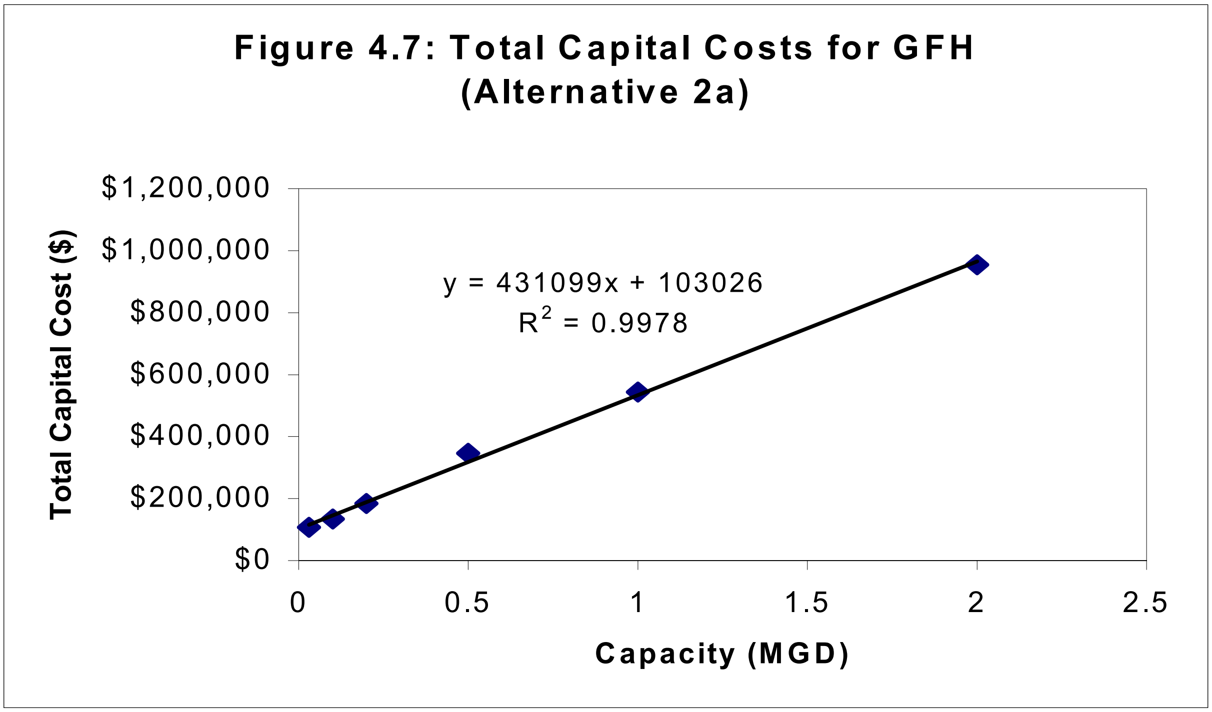


Figure 4.7: Total Capital Costs for GFH
(Alternative 2a)
Total Capital Cost ($)
$1,200,000
$1,000,000
$800,000
$600,000
$400,000
$200,000
$0
y = 431099x + 103026
R2 = 0.9978
0
0.5
1
1.5
2
2.5
Capacity (MGD)

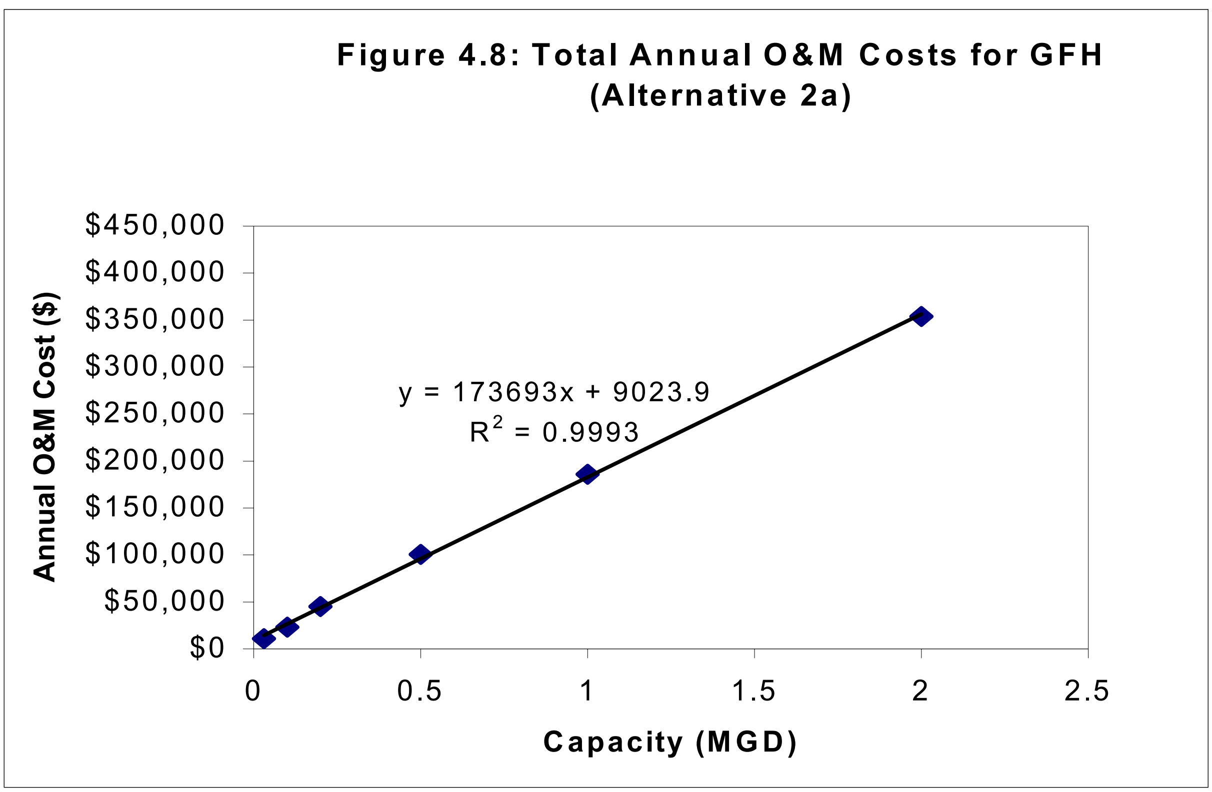


Figure 4.8: Total Annual O&M Costs for GFH
(Alternative 2a)
Annual O&M Cost ($)
$450,000
$400,000
$350,000
$300,000
$250,000
$200,000
$150,000
$100,000
$50,000
$0
y = 173693x + 9023.9
R2 = 0.9993
0
0.5
1
1.5
2
2.5
Capacity (MGD)

Figure 4.9: Total Capital Costs for GFH (Alternative 2b)

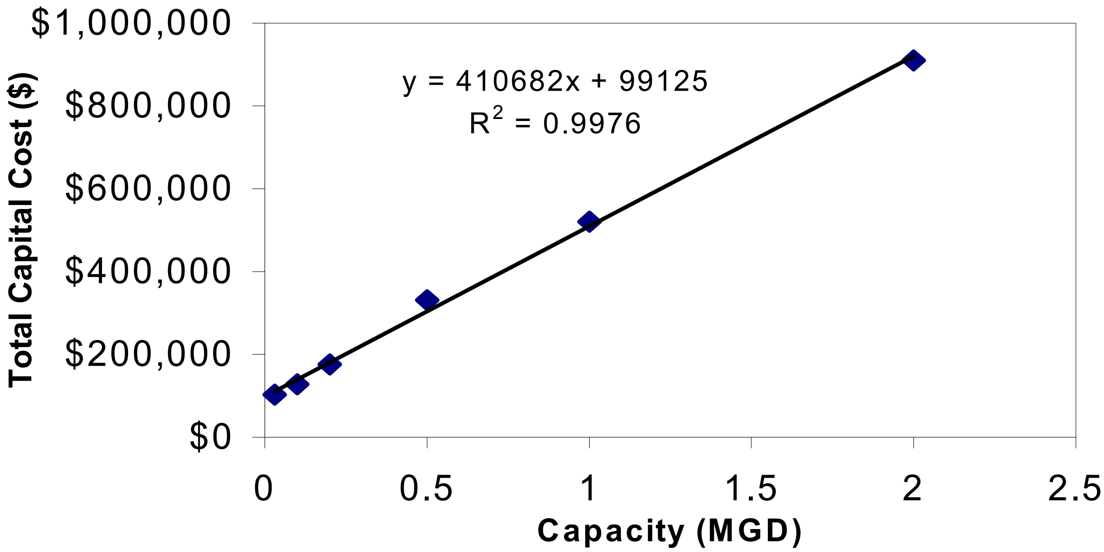
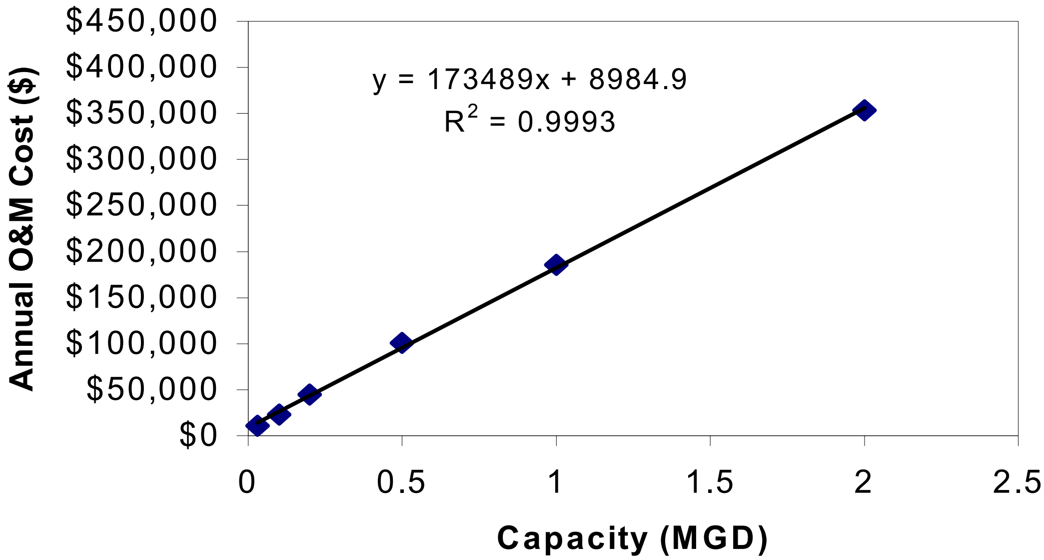


Figure 4.10: Total Annual O&M Costs for GFH (Alternative 2b)



4.4.3 Alternatives 3a and 3b Cost Models

4.4.3.1 System Design Criteria

The schematics for Alternatives 3a and 3b are shown in Figures 4.11 and 4.12, respectively. The design flow through the treatment unit is 21-1389 gpm and two 5 minute EBCT contactors in series is the recommended treatment configuration. The Fe-AA column was assumed to operate 100% of the time in computing O&M costs. The vessel diameter is 2-12 ft, based on the system flow and the media depth in the column would be 4 ft. The pressure drop through the system is 20 psi. The average operating pressure is 100 psi for Alternative 3a and 50 psi for Alternative 3b. For small systems, a manually operated cartridge filter is used. Acid and caustic facilities are required for pH adjustment to 6.5 and readjustment after treatment. Under these operating conditions, the Fe-AA column is expected to last a period of 105 days before breakthrough for a raw water with 25 ppb influent arsenic and no significant interferences. After the first column breaks through, the media is replaced and the flow is rerouted so that the raw water flows to the second column first. The adsorption media is backwashed monthly and the backwash volume is approximately 8 BVs. A steel tank is used for backwash recovery. For large systems, the spent media is stored on-site in a holding area and disposed to a municipal landfill as it is not considered hazardous. Approximately 100-6800 cubic feet of media (4,500-305,000 lbs) is disposed of every year, based on the system capacity. No spent media handling facilities are provided for treatment plants <0.5 MGD (tanker facilities provided by media vendor during changeout). The system design criteria for two column Fe-AA treatment is shown in Table 4.13.

4.4.3.2 Cost Evaluation

A summary of estimated capital costs and annual O&M costs for Alternatives 3a are shown in Tables 4.14 and 4.15, respectively. A summary of estimated capital costs and annual O&M costs for Alternatives 3b are shown in Tables 4.16 and 4.17, respectively. These estimated costs were plotted as a function of system design flow to develop capital and O&M cost curves to estimate costs for systems of various capacities throughout Arizona. The capital and O&M cost curves for Alternatives 3a are as shown in Figures 4.13 and 4.14, respectively. The capital and O&M cost curves for Alternatives 3b are as shown in Figures 4.15 and 4.16, respectively.

Table 4.13: Design Criteria for Two Column Fe-AA Treatment (3a and 3b)

Parameter	Units	Value
Flow	gpm	21-1389
Average Influent Arsenic level	ppb	25
No. of Treatment Vessels		2
Vessel Configuration		series
EBCT (each vessel)	min	5
Vessel Diameter	ft	2-12
Media Depth	ft	4
Vessel Height (side shell)	ft	7.5
Operating Pressure	psi	100 (Alternative 3a) 50 psi (Alternative 3b)
Maximum Headloss	psi	20
Operating pH	std. units	6.5
Operating time until arsenic breakthrough[1]	days	105
Acid/Caustic facilities required?		Yes[2]
Backwash Equalization Basin	BVs	8
Backwash Disposal		Landfill
Backwash Frequency		Monthly
Clearwell Detention Time	min	10

[1]Media replacement interval based on continuous operation

[2]pH adjustment necessary for Fe-AA based on pilot testing data

Table 4.14: Estimated Capital Costs for Alternative 3a (Two Column Treatment with Fe-AA - direct pumping into system)

	Capacity in MGD					
Fe-AA System Facilities Costs	0.03	0.1	0.2	0.5	1.0	2.0
Booster Pumping/ Straining	$7,500	$7,500	$8,550	$18,000	$28,000	$32,000
Residuals Handling Facilities	$3,267	$8,956	$13,711	$39,149	$63,778	$71,398
Fe-AA System Facilities	$49,414	$64,713	$106,025	$161,563	$254,126	$646,251
Chemical Feed Faciliites	$10,854	$17,979	$33,358	$66,495	$122,590	$237,380
Building	$32,000	$32,000	$32,000	$38,400	$51,840	$108,000
Piping, I&C, Electrical, Yard Piping Allowances	$28,414	$39,659	$64,658	$114,083	$187,397	$394,812
Total Facility Cost, $	$131,448	$170,806	$258,302	$437,689	$707,731	$1,489,841
Contingency, 20%	$26,290	$34,161	$51,660	$87,538	$141,546	$297,968
Taxes & Bonding, 8.5%	$13,408	$17,422	$26,347	$44,644	$72,189	$151,964
Total Estimated Fe-AA Facility Cost	$171,145	$222,389	$336,309	$569,872	$921,466	$1,939,773

Table 4.15: Annual O&M Costs for Alternative 3a (Two Column Treatment with Fe-AA - direct pumping into system)

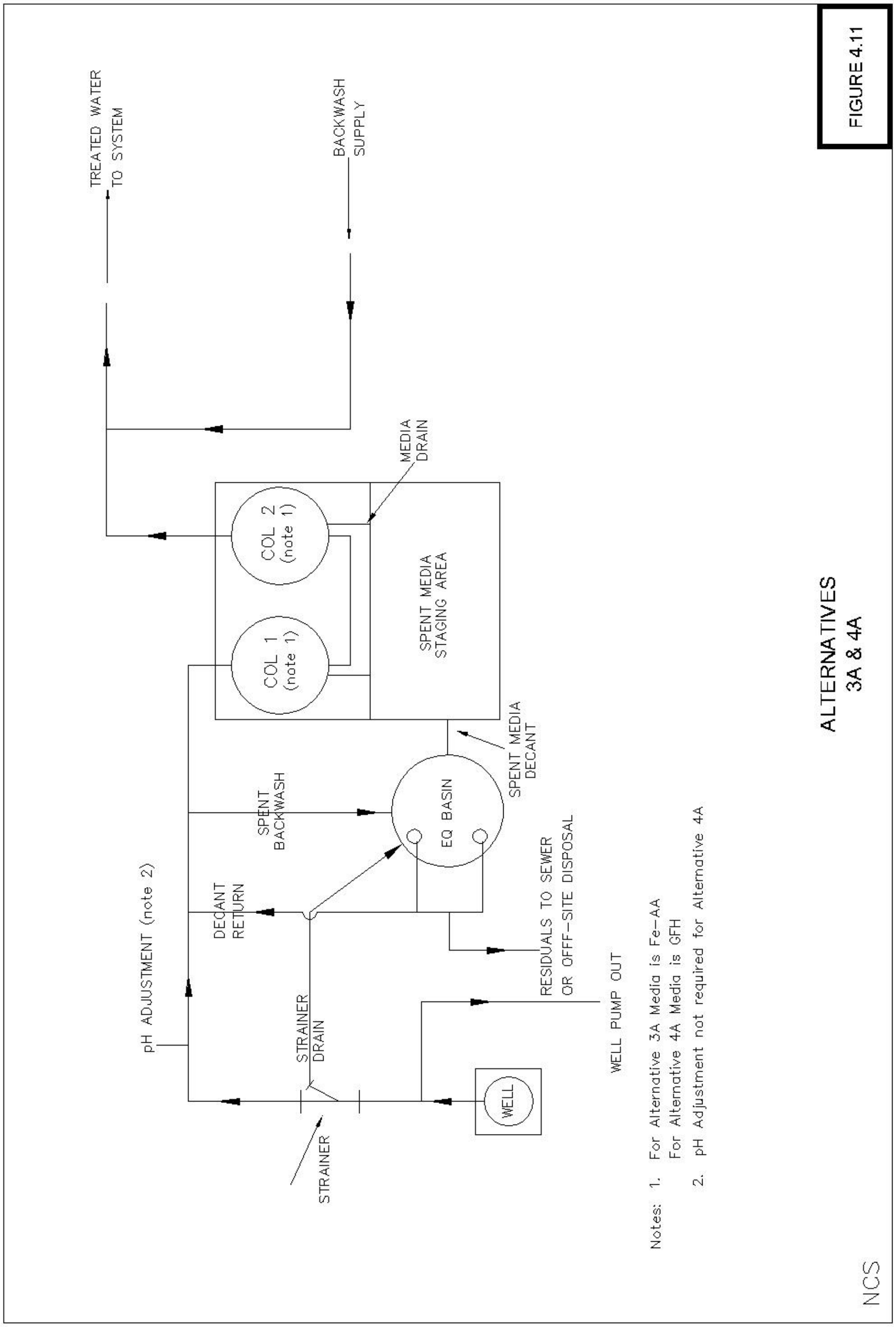
	Capacity in MGD					
Facility assumed to operate 100% of time	0.03	0.1	0.2	0.5	1.0	2.0
Annual Power Cost, $/yr	$539	$1,617	$2,694	$2,828	$5,637	$8,446
H2SO4 Cost, $/yr	$137	$457	$913	$2,283	$4,566	$9,132
NaOH Cost, $/yr	$310	$1,035	$2,070	$5,175	$10,350	$20,700
Annual Media Replacement Costs, $/yr	$4,110	$13,698	$27,397	$68,492	$136,985	$273,969
Media Replacement Service Cost, $	$2,500	$2,500	$5,000	$8,000	$10,000	$15,000
Waste Media Disposal Costs, $/yr	$301	$1,005	$2,009	$5,023	$10,046	$20,091
Total Estimated Labor Costs, $/yr	$2,059	$2,059	$4,493	$8,299	$8,299	$8,299
Equipment Maintenance Costs, $/yr	$1,711	$2,224	$3,363	$5,699	$9,215	$19,398
Arsenic Analysis cost, $/yr	$90	$90	$90	$90	$90	$90
Total Estimated Annual O&M Costs, $/yr	$9,258	$22,185	$43,030	$97,889	$185,187	$360,126
Unit Annual O&M Costs, $/1000 gal	$0.85	$0.61	$0.59	$0.54	$0.51	$0.49

Table 4.16: Estimated Capital Costs for Alternative 3b (Two Column Treatment using Fe-AA - pumping into existing on-site storage tank and repumping into system)

Fe-AA System Facilities Costs	Capacity in MGD					
	0.03	0.1	0.2	0.5	1.0	2.0
Booster Pumping/ Straining	$7,500	$7,500	$8,550	$18,000	$28,000	$32,000
Residuals Handling Facilities	$3,267	$8,956	$13,711	$39,149	$63,778	$71,398
Fe-AA System Facilities	$44,614	$58,713	$96,365	$147,763	$233,426	$591,051
Chemical Feed Faciliites	$10,854	$17,979	$33,358	$66,495	$122,590	$237,380
Building	$32,000	$32,000	$32,000	$38,400	$51,840	$108,000
Piping, I&C, Electrical, Yard Piping Allowances	$26,494	$37,259	$60,794	$108,563	$179,117	$372,732
Total Facility Cost, $	$124,728	$162,406	$244,778	$418,369	$678,751	$1,412,561
Contingency, 20%	$24,946	$32,481	$48,956	$83,674	$135,750	$282,512
Taxes & Bonding, 8.5%	$12,722	$16,565	$24,967	$42,674	$69,233	$144,081
Total Estimated Fe-AA Facility Cost	$162,396	$211,453	$318,701	$544,717	$883,734	$1,839,154

Table 4.17: Annual O&M Costs for Alternative 3b (Two Column Treatment using Fe-AA - pumping into existing on-site storage tank and repumping into system)

Facility assumed to operate 100% of time	Capacity in MGD					
	0.03	0.1	0.2	0.5	1.0	2.0
Annual Power Cost, $/yr	$539	$1,617	$2,694	$2,828	$5,637	$8,446
H2SO4 Cost, $/yr	$137	$457	$913	$2,283	$4,566	$9,132
NaOH Cost, $/yr	$310	$1,035	$2,070	$5,175	$10,350	$20,700
Annual Media Replacement Costs, $/yr	$4,110	$13,698	$27,397	$68,492	$136,985	$273,969
Media Replacement Service Cost, $	$2,500	$2,500	$5,000	$8,000	$10,000	$15,000
Waste Media Disposal Costs, $/yr	$301	$1,005	$2,009	$5,023	$10,046	$20,091
Total Estimated Labor Costs, $/yr	$2,059	$2,059	$4,493	$8,299	$8,299	$8,299
Equipment Maintenance Costs, $/yr	$1,624	$2,115	$3,187	$5,447	$8,837	$18,392
Arsenic Analysis cost, $/yr	$90	$90	$90	$90	$90	$90
Total Estimated Annual O&M Costs, $/yr	$9,170	$22,075	$42,853	$97,638	$184,810	$359,119
Unit Annual O&M Costs, $/1000 gal	$0.84	$0.60	$0.59	$0.54	$0.51	$0.49



ALTERNATIVES 3A & 4A

FIGURE 4.11

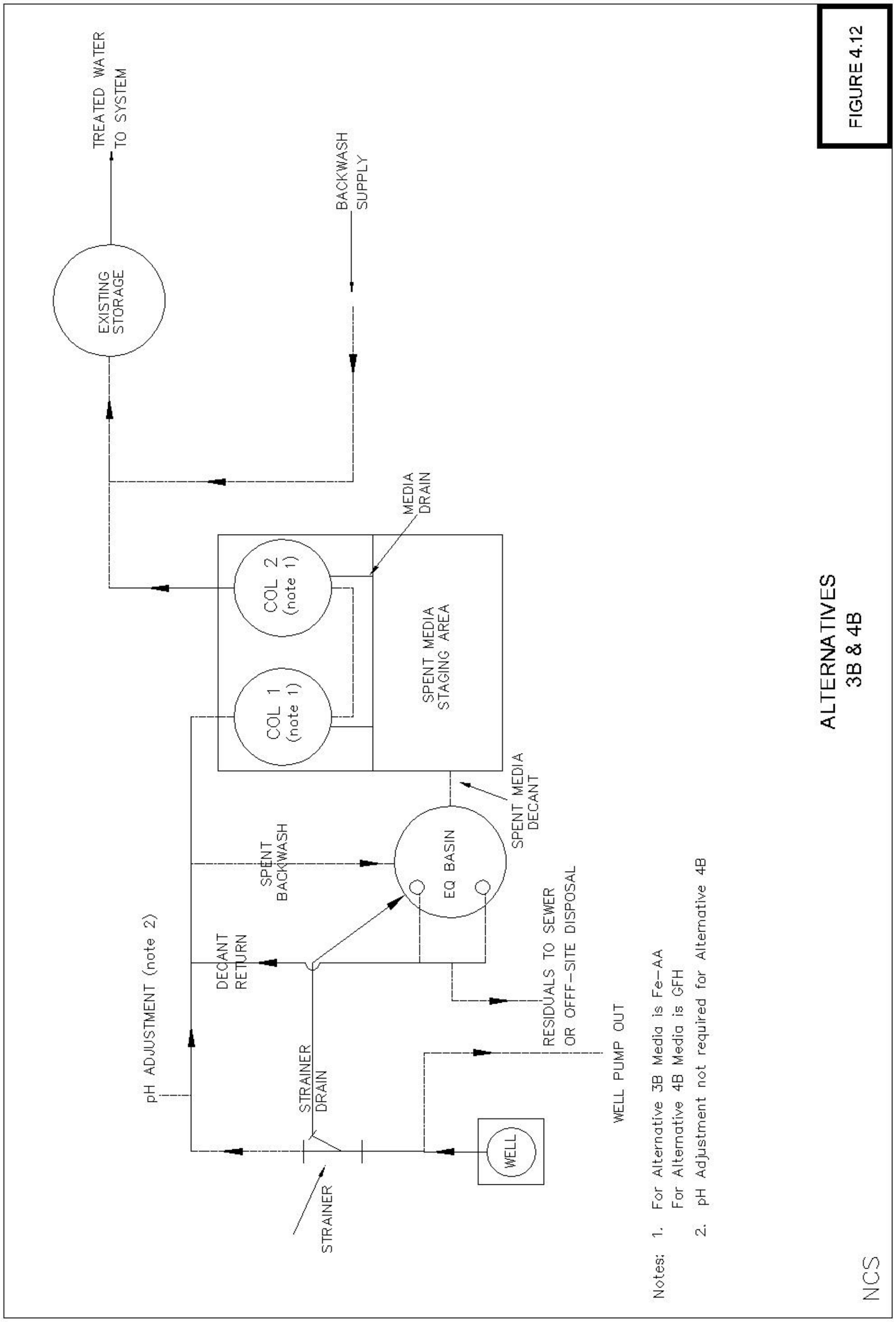

TREATED WATER TO SYSTEM
EXISTING STORAGE
BACKWASH SUPPLY
MEDIA DRAIN
COL 2 (note 1)
COL 1 (note 1)
SPENT MEDIA STAGING AREA
SPENT MEDIA DECANT
EQ BASIN
SPENT BACKWASH
DECANT RETURN
pH ADJUSTMENT (note 2)
RESIDUALS TO SEWER OR OFFF-SITE DISPOSAL
WELL PUMP OUT
STRAINER DRAIN
STRAINER
WELL
Notes: 1. For Alternative 3B Media is Fe-AA
For Alternative 4B Media is GFH
2. pH Adjustment not required for Alternative 4B
NCS
ALTERNATIVES 3B & 4B
FIGURE 4.12

Figure 4.13: Total Capital Costs for Fe-AA (Alternative 3a)

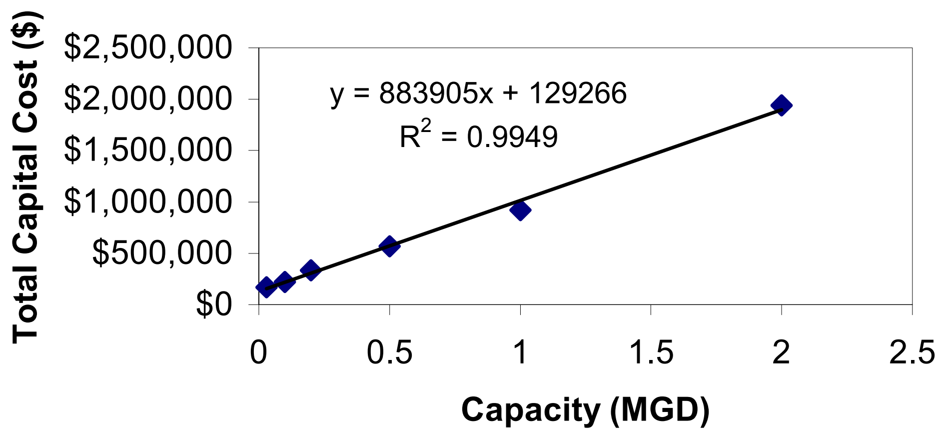


Figure 4.14: Total Annual O&M Costs for Fe-AA (Alternative 3a)

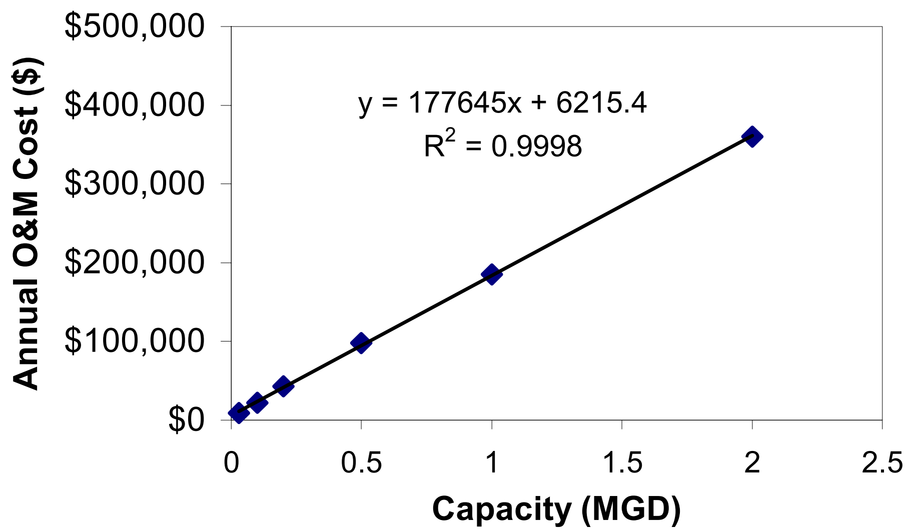


Figure 4.15: Total Capital Costs for Fe-AA (Alternative 3b)

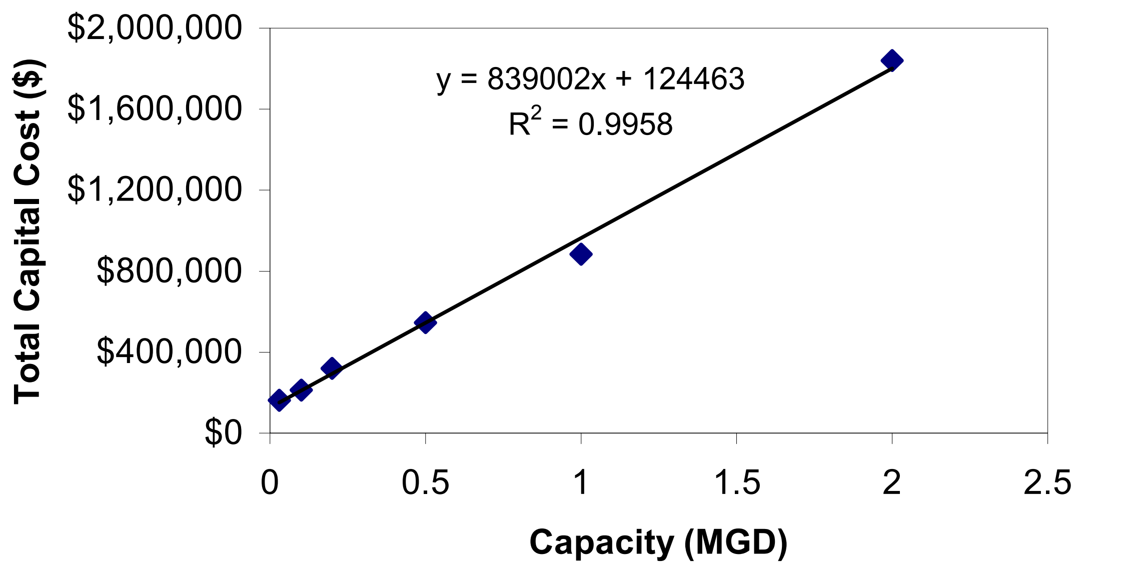
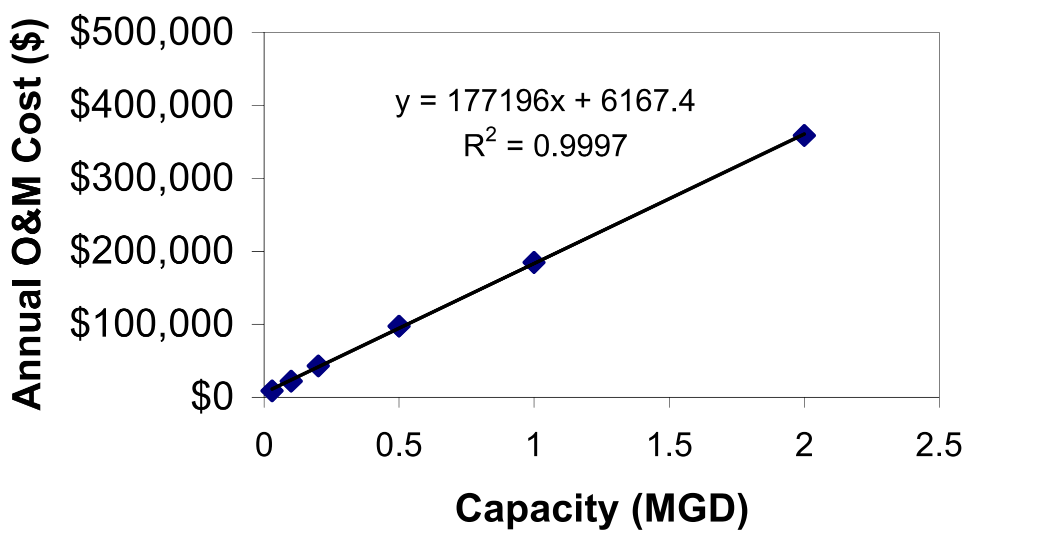


Figure 4.16: Total Annual O&M Costs for Fe-AA (Alternative 3b)



4.4.4 Alternatives 3c and 3d Cost Models

4.4.4.1 System Design Criteria

The schematics for Alternatives 3c and 3d are shown in Figures 4.17 and 4.18, respectively. These alternatives are for systems with arsenic concentrations <20 ppb using partial stream treatment. The only difference between the two options is that under Alternative 3c, an existing storage tank is present, while in Alternative 3d, a new clearwell and booster station are constructed after treatment. The design flow through the treatment unit is 21-1389 gpm and two 5 minute EBCT contactors in series is the recommended treatment configuration. The Fe-AA column was assumed to operate 100% of the time in computing O&M costs. The vessel diameter is 2-12 ft, based on the system flow. The media depth in the column is 4 ft. The pressure drop through the system is 20 psi. The average operating pressure is 50 psi. Acid and caustic facilities are required for pH adjustment to 6.5 and readjustment after treatment. Under these operating conditions, the Fe-AA column is expected to last a period of 157 days before breakthrough for a raw water with 15 ppb influent arsenic and no significant parameters. After the first column breaks through, the media is replaced and the flow is rerouted so that the raw water flows to the second column first. The adsorption media is backwashed monthly and the backwash volume is approximately 8 BVs. A steel tank is used for backwash recovery. For large systems, the spent media is stored on-site in a holding area and disposed to a municipal landfill as it is not considered hazardous. Approximately 67-4,500 cubic feet of media (3,000-203,000 lbs) will have to be disposed of every year, based on the system capacity. The system design criteria for two column Fe-AA treatment is shown in Table 4.18.

4.4.4.2 Cost Evaluation

A summary of estimated capital costs and annual O&M costs for Alternative 3c are shown in Tables 4.19 and 4.20, respectively. A summary of estimated capital costs and annual O&M costs for Alternative 3d are shown in Tables 4.21 and 4.22, respectively. These estimated costs were plotted as a function of system design flow to develop capital and O&M cost curves to estimate costs for systems of various capacities throughout Arizona. The capital and O&M cost curves for Alternative 3c are as shown in Figures 4.19 and 4.20, respectively. The capital and O&M cost curves for Alternative 3d are as shown in Figures 4.21 and 4.22, respectively.

Table 4.18: Design Criteria for Two Column Fe-AA Treatment (3c and 3d)

Parameter	Units	Value
Flow	gpm	21-1389
Average Influent Arsenic level	ppb	15
No. of Treatment Vessels		2
Vessel Configuration		series
EBCT (each vessel)	min	5
Vessel Diameter	ft	2-12
Media Depth	ft	4
Vessel Height (side shell)	ft	6.5
Operating Pressure	psi	50
Maximum Headloss	psi	20
Operating pH	std. units	6.5
Operating time until arsenic breakthrough[1]	days	157
Acid/Caustic facilities required?		Yes[2]
Backwash Equalization Basin	BVs	8
Spent Media Disposal		Landfill
Backwash Frequency		Monthly
Clearwell Detention Time	min	10

[1]Media replacement interval based on continuous operation

[2]pH adjustment necessary for Fe-AA based on pilot testing data

Table 4.19: Estimated Capital Costs for Alternative 3c (Two Column Partial Stream Treatment using Fe-AA - pumping into existing on-site storage tank and repumping into system)

Fe-AA System Facilities Costs	Capacity in MGD 0.03	0.1	0.2	0.5	1.0	2.0
Booster Pumping/ Straining	$7,500	$7,500	$8,550	$18,000	$28,000	$32,000
Residuals Handling Facilities	$3,267	$8,956	$13,711	$39,149	$63,778	$71,398
Fe-AA System Facilities	$53,254	$69,513	$111,485	$169,363	$265,826	$677,451
Chemical Feed Faciliites	$10,854	$17,979	$33,358	$66,495	$122,590	$237,380
Building	$32,000	$32,000	$32,000	$38,400	$51,840	$108,000
Piping, I&C, Electrical, Yard Piping Allowances	$29,950	$41,579	$66,842	$117,203	$192,077	$407,292
Total Facility Cost, $	$136,824	$177,526	$265,946	$448,609	$724,111	$1,533,521
Contingency, 20%	$27,365	$35,505	$53,189	$89,722	$144,822	$306,704
Taxes & Bonding, 8.5%	$13,956	$18,108	$27,126	$45,758	$73,859	$156,419
Total Estimated Fe-AA Facility Cost	$178,145	$231,139	$346,262	$584,089	$942,792	$1,996,644

Table 4.20: Annual O&M Costs for Alternative 3c (Two Column Partial Stream Treatment using Fe-AA - pumping into existing on-site storage tank and repumping into system)

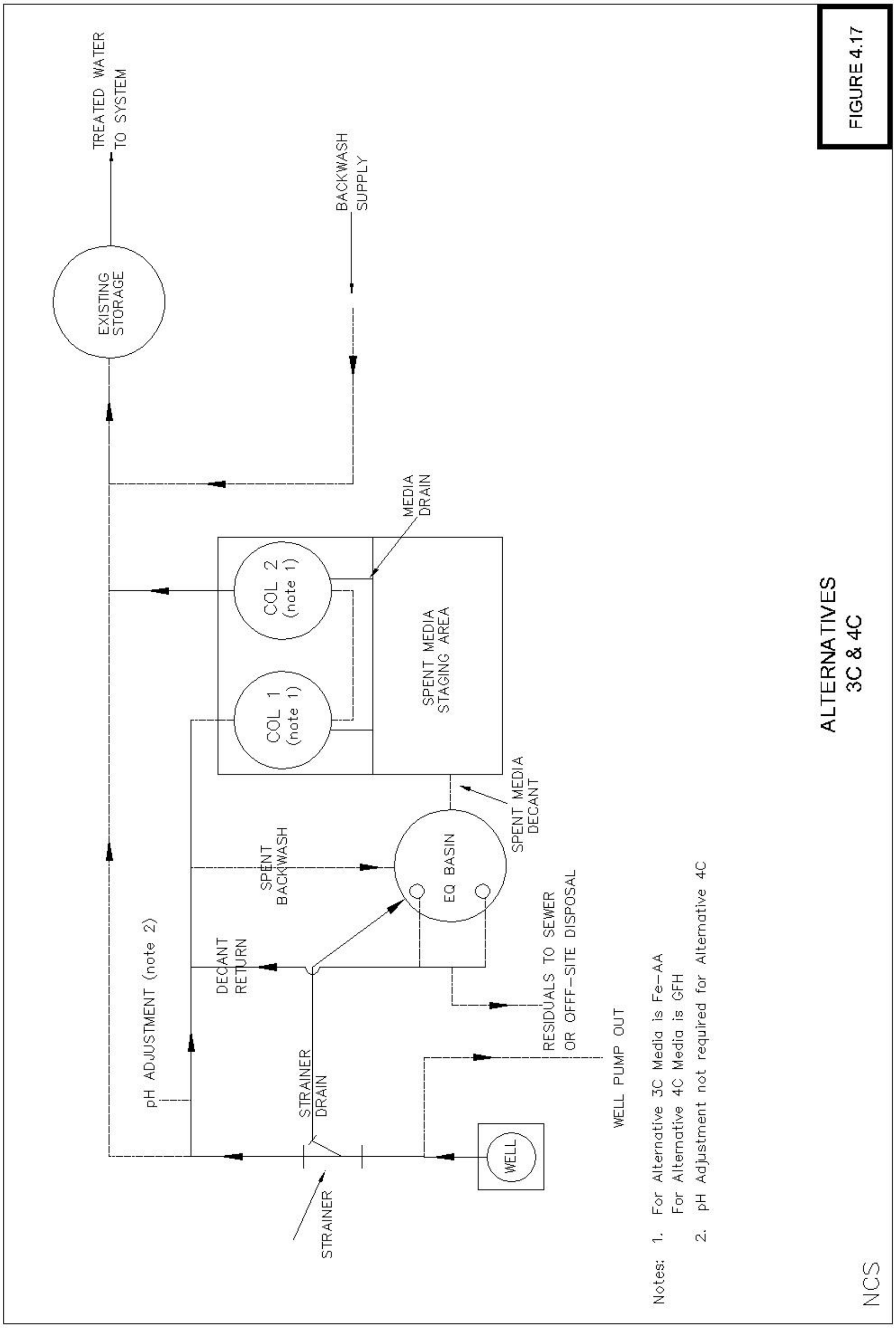
Facility assumed to operate 100% of time	Capacity in MGD 0.03	0.1	0.2	0.5	1.0	2.0
Annual Power Cost, $/yr	$539	$1,617	$2,694	$2,828	$5,637	$8,446
H2SO4 Cost, $/yr	$137	$457	$913	$2,283	$4,566	$9,132
NaOH Cost, $/yr	$310	$1,035	$2,070	$5,175	$10,350	$20,700
Annual Media Replacement Costs, $/yr	$2,740	$9,132	$18,265	$45,662	$91,323	$182,646
Media Replacement Service Cost, $	$2,500	$2,500	$5,000	$8,000	$10,000	$15,000
Waste Media Disposal Costs, $/yr	$201	$670	$1,339	$3,349	$6,697	$13,394
Total Estimated Labor Costs, $/yr	$2,059	$2,059	$4,493	$8,299	$8,299	$8,299
Equipment Maintenance Costs, $/yr	$1,781	$2,311	$3,463	$5,841	$9,428	$19,966
Arsenic Analysis cost, $/yr	$90	$90	$90	$90	$90	$90
Total Estimated Annual O&M Costs, $/yr	$7,768	$17,281	$33,237	$73,436	$136,301	$262,584
Unit Annual O&M Costs, $/1000 gal	$0.71	$0.47	$0.46	$0.40	$0.37	$0.36

Table 4.21: Estimated Capital Costs for Alternative 3d (Two Column Partial Stream Treatment using Fe-AA - pumping into new storage tank and repumping into system)

Fe-AA System Facilities Costs	Capacity in MGD					
	0.03	0.1	0.2	0.5	1.0	2.0
Booster Pumping/ Straining	$61,260	$78,900	$97,650	$252,900	$322,780	$402,500
Residuals Handling Facilities	$3,267	$8,956	$13,711	$39,149	$63,778	$71,398
Fe-AA System Facilities	$53,254	$69,513	$111,485	$169,363	$265,826	$677,451
Chemical Feed Faciliites	$10,854	$17,979	$33,358	$66,495	$122,590	$237,380
Building	$32,000	$32,000	$32,000	$38,400	$51,840	$108,000
Piping, I&C, Electrical, Yard Piping Allowances	$51,454	$70,139	$102,482	$211,163	$309,989	$555,492
Total Facility Cost, $	$212,088	$277,486	$390,686	$777,469	$1,136,803	$2,052,221
Contingency, 20%	$42,418	$55,497	$78,137	$155,494	$227,361	$410,444
Taxes & Bonding, 8.5%	$21,633	$28,304	$39,850	$79,302	$115,954	$209,327
Total Estimated Fe-AA Facility Cost	$276,138	$361,287	$508,673	$1,012,265	$1,480,117	$2,671,991

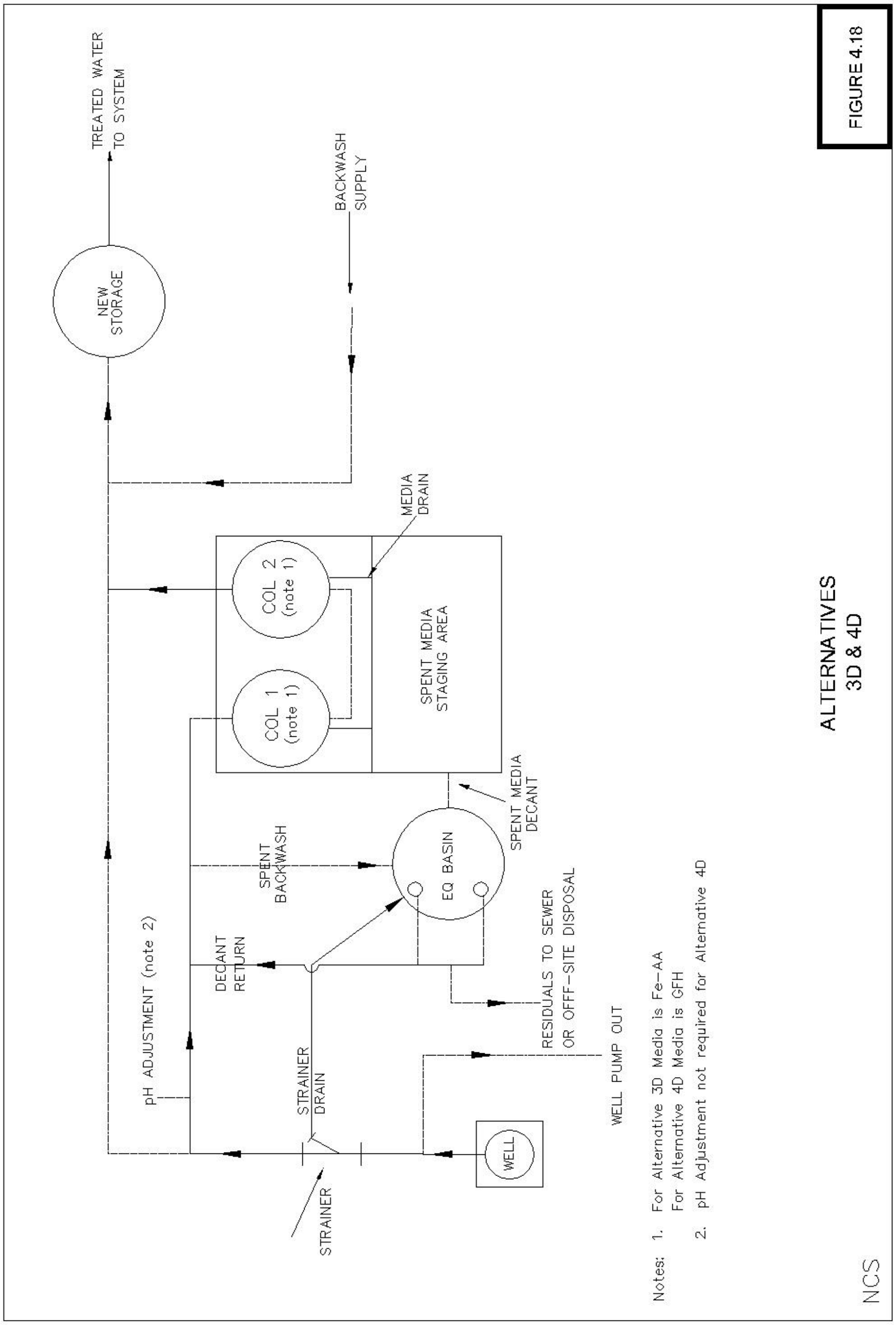
Table 4.22: Annual O&M Costs for Alternative 3d (Two Column Partial Stream Treatment using Fe-AA - pumping into new storage tank and repumping into system)

Facility assumed to operate 100% of time	Capacity in MGD					
	0.03	0.1	0.2	0.5	1.0	2.0
Annual Power Cost, $/yr	$539	$1,617	$2,694	$2,828	$5,637	$8,446
H2SO4 Cost, $/yr	$137	$457	$913	$2,283	$4,566	$9,132
NaOH Cost, $/yr	$310	$1,035	$2,070	$5,175	$10,350	$20,700
Annual Media Replacement Costs, $/yr	$2,740	$9,132	$18,265	$45,662	$91,323	$182,646
Media Replacement Service Cost, $	$2,500	$2,500	$5,000	$8,000	$10,000	$15,000
Waste Media Disposal Costs, $/yr	$201	$670	$1,339	$3,349	$6,697	$13,394
Total Estimated Labor Costs, $/yr	$2,059	$2,059	$4,493	$8,299	$8,299	$8,299
Equipment Maintenance Costs, $/yr	$2,761	$3,613	$5,087	$10,123	$14,801	$26,720
Arsenic Analysis cost, $/yr	$90	$90	$90	$90	$90	$90
Total Estimated Annual O&M Costs, $/yr	$8,838	$18,672	$34,951	$77,808	$141,764	$269,428
Unit Annual O&M Costs, $/1000 gal	$0.81	$0.51	$0.48	$0.43	$0.39	$0.37



ALTERNATIVES
3C & 4C

FIGURE 4.17


TREATED WATER
TO SYSTEM
NEW
STORAGE
BACKWASH
SUPPLY
MEDIA
DRAIN
COL 2
(note 1)
COL 1
(note 1)
SPENT MEDIA
STAGING AREA
SPENT MEDIA
DECANT
SPENT
BACKWASH
EQ BASIN
pH ADJUSTMENT (note 2)
DECANT
RETURN
RESIDUALS TO SEWER
OR OFFF-SITE DISPOSAL
STRAINER
DRAIN
WELL PUMP OUT
WELL
STRAINER
Notes: 1. For Alternative 3D Media is Fe-AA
For Alternative 4D Media is GFH
2. pH Adjustment not required for Alternative 4D
NCS
ALTERNATIVES
3D & 4D
FIGURE 4.18

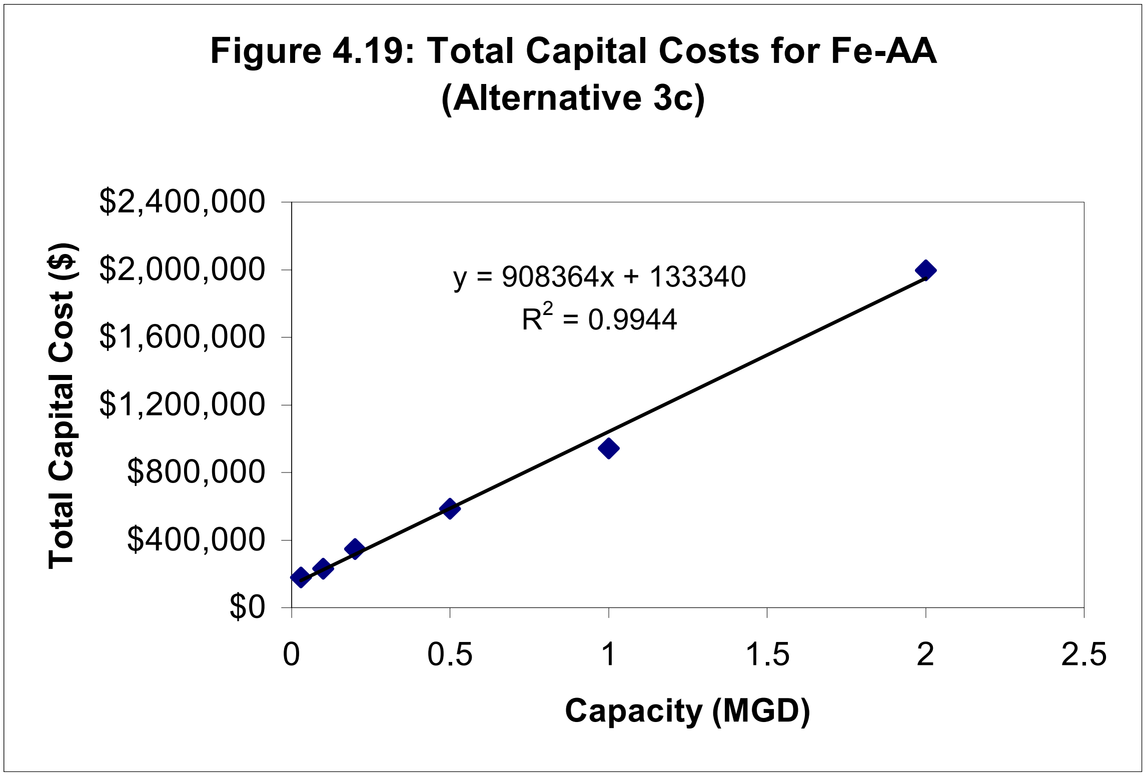


Figure 4.19: Total Capital Costs for Fe-AA
(Alternative 3c)
y = 908364x + 133340
R2 = 0.9944
Total Capital Cost ($)
$2,400,000
$2,000,000
$1,600,000
$1,200,000
$800,000
$400,000
$0
0
0.5
1
1.5
2
2.5
Capacity (MGD)

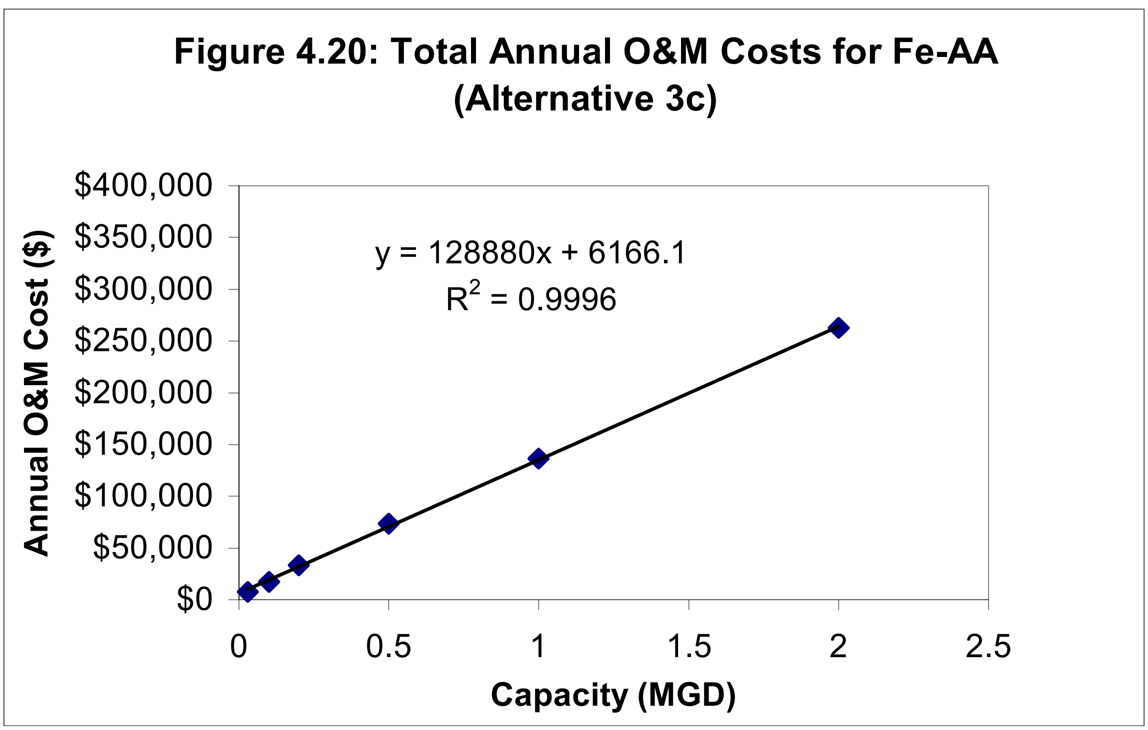


Figure 4.20: Total Annual O&M Costs for Fe-AA
(Alternative 3c)
y = 128880x + 6166.1
R2 = 0.9996
Annual O&M Cost ($)
$400,000
$350,000
$300,000
$250,000
$200,000
$150,000
$100,000
$50,000
$0
0
0.5
1
1.5
2
2.5
Capacity (MGD)

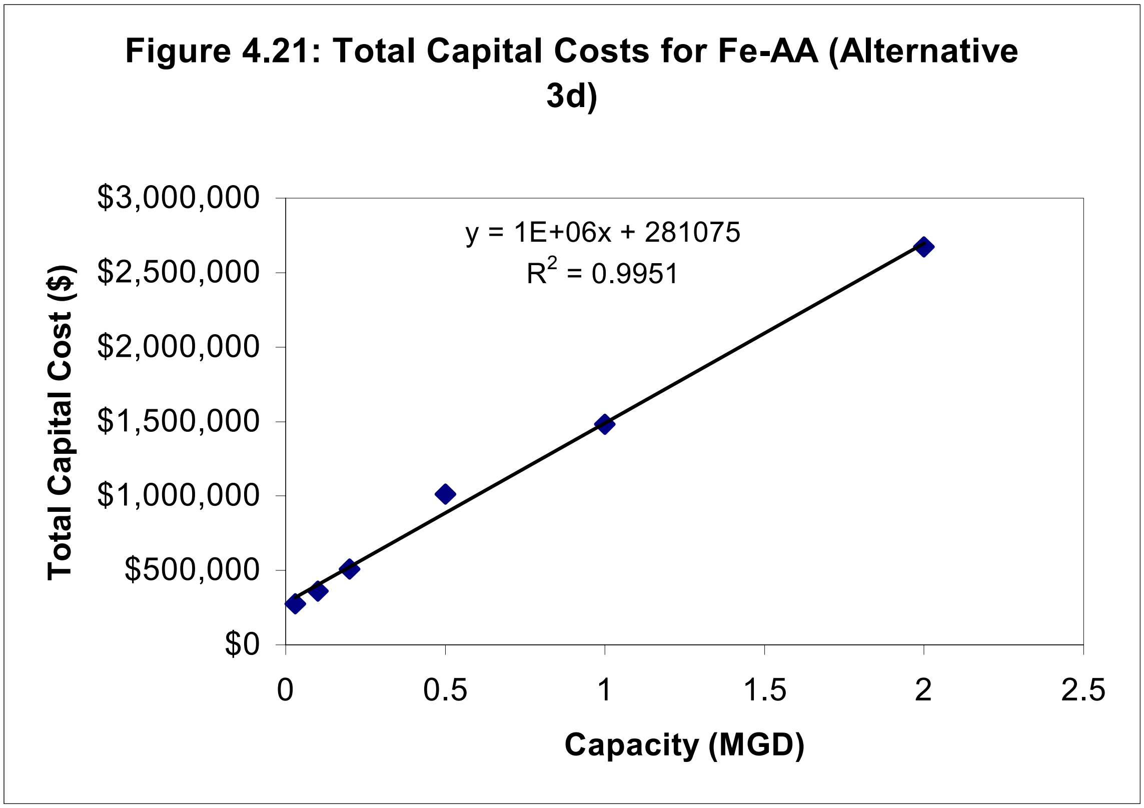


Figure 4.21: Total Capital Costs for Fe-AA (Alternative 3d)
y = 1E+06x + 281075
R2 = 0.9951
Total Capital Cost ($)
$3,000,000
$2,500,000
$2,000,000
$1,500,000
$1,000,000
$500,000
$0
0
0.5
1
1.5
2
2.5
Capacity (MGD)

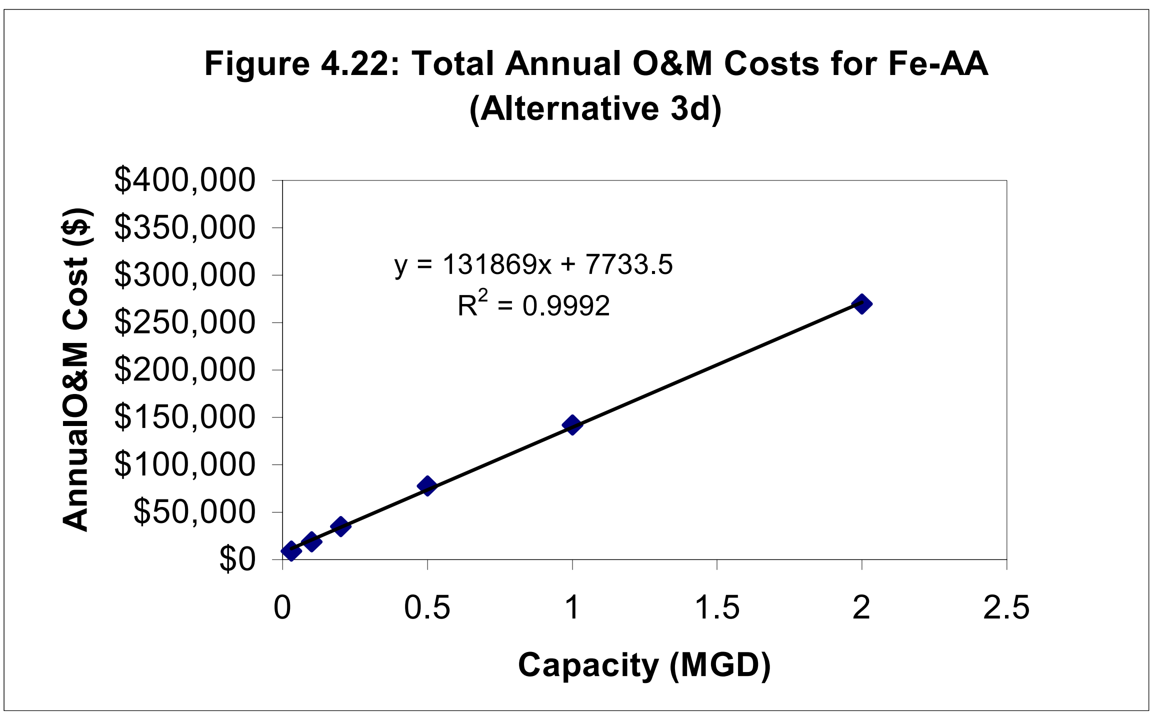


Figure 4.22: Total Annual O&M Costs for Fe-AA (Alternative 3d)
y = 131869x + 7733.5
R2 = 0.9992
AnnualO&M Cost ($)
$400,000
$350,000
$300,000
$250,000
$200,000
$150,000
$100,000
$50,000
$0
0
0.5
1
1.5
2
2.5
Capacity (MGD)

4.4.5 Alternatives 4a and 4b Cost Models

4.4.5.1 System Design Criteria

The schematics for Alternatives 4a and 4b are shown in Figures 4.11 and 4.12, respectively. The design flow through the treatment unit is 21-1389 gpm and two 2.5 minute EBCT contactors is the recommended treatment configuration. The granular iron media column was assumed to operate 100% of the time in computing the O&M costs. The vessel diameter is 2-12 ft, based on the system flow. The media depth in the column is 2.7 ft. The pressure drop through the system is 20 psi. The average operating pressure is 100 psi for Alternative 4a and 50 psi for Alternative 4b. For small systems, a manually operated cartridge filter is used. No pH adjustment is required. Under these operating conditions, the granular iron media column is expected to last a period of 107 days before breakthrough for a raw water with 25 ppb influent arsenic and no significant interferences. After the column breaks through, the media is replaced. The granular iron media is backwashed monthly and the backwash volume is approximately 13 BVs. A steel tank is used for backwash recovery. For large systems, the spent media is stored on-site in a holding area for subsequent disposal to a municipal landfill as it is not considered hazardous. Approximately 75-5,067 cubic feet of media (3,400-228,000 lbs) will have to be disposed of every year, based on the system capacity. No spent media facilities are provided for treatment plants <0.5 MGD (tanker facilities provided by media vendor during changeout). The system design criteria for two column granular iron media treatment is shown in Table 4.23.

4.4.5.2 Cost Evaluation

A summary of estimated capital costs and annual O&M costs for Alternative 4a are shown in Tables 4.24 and 4.25, respectively. A summary of estimated capital costs and annual O&M costs for Alternative 4b are shown in Tables 4.26 and 4.27, respectively. These estimated costs were plotted as a function of system design flow to develop capital and O&M cost curves to estimate costs for systems of various capacities throughout Arizona. The capital and O&M cost curves for Alternative 4a are shown in Figures 4.23 and 4.24, respectively. The capital and O&M cost curves for Alternative 4b are as shown in Figures 4.25 and 4.26, respectively.

Table 4.23: Design Criteria for Two Column Granular Iron Media Treatment (4a and 4b)

Parameter	Units	Value
Flow	gpm	21-1389
Average Arsenic level	ppb	25
No. of Treatment Vessels		2
Vessel Configuration		series
EBCT (each vessel)	min	2.5
Vessel Diameter	ft	2-12
Media Depth	ft	2.7
Vessel Height (side shell)	ft	6
Operating Pressure	psi	100 (Alternative 4a) 50 (Alternative 4b)
Maximum Headloss	psi	20
Maximum Operating pH	std. units	8.0
Operating time until arsenic breakthrough[1]	days	107
Acid/Caustic facilities required?		No[2]
Backwash Equalization Basin	BVs	13
Spent Media Disposal		Landfill
Backwash Frequency		Monthly
Clearwell Detention Time	min	10

[1]Media replacement interval based on continuous operation

[2]pH adjustment not necessary for granular iron media for waters up to pH 8.0

Table 4.24: Estimated Capital Costs for Alternative 4a (Two Column Treatment using Iron Media - direct pumping into system)

	Capacity in MGD					
GFH System Facilities Costs	0.03	0.1	0.2	0.5	1.0	2.0
Residuals Handling Facilities	$2,954	$7,914	$11,628	$36,545	$58,569	$66,189
Booster Pumping/ Straining	$7,500	$7,500	$8,550	$18,000	$28,000	$32,000
GFH System Facilities	$51,008	$70,027	$116,053	$215,734	$348,667	$697,335
Building	$32,000	$32,000	$32,000	$38,400	$51,840	$108,000
Piping, I&C, Electrical, Yard Piping Allowances	$24,585	$34,176	$54,493	$108,111	$174,095	$318,210
Total Facility Cost, $	$118,047	$151,617	$222,724	$416,790	$661,172	$1,221,734
Contingency, 20%	$23,609	$30,323	$44,545	$83,358	$132,234	$244,347
Taxes & Bonding, 8.5%	$12,041	$15,465	$22,718	$42,513	$67,439	$124,617
Total Estimated GFH Facility Cost	$153,697	$197,405	$289,986	$542,660	$860,845	$1,590,698

Table 4.25: Annual O&M Costs for Alternative 4a (Two Column Treatment using Iron Media - direct pumping into system)

	Capacity in MGD					
Facility assumed to operate 100% of time	0.03	0.1	0.2	0.5	1.0	2.0
Annual Power Cost, $/yr	$539	$1,617	$2,694	$2,826	$5,635	$11,253
Annual Media Replacement Costs, $/yr	$6,849	$22,831	$45,662	$114,154	$228,308	$456,615
Media Replacement Service Cost, $	$2,500	$2,500	$5,000	$8,000	$10,000	$15,000
Waste Media Disposal Costs, $/yr	$120	$264	$540	$1,320	$2,640	$5,280
Total Estimated Labor Costs, $/yr	$2,059	$2,059	$4,493	$8,299	$8,299	$8,299
Equipment Maintenance Costs, $/yr	$1,537	$1,974	$2,900	$5,427	$8,608	$15,907
Arsenic Analysis cost, $/yr	$60	$60	$60	$60	$60	$60
Total Estimated Annual O&M Costs, $/yr	$13,664	$31,304	$61,349	$140,085	$263,550	$512,414
Unit Annual O&M Costs, $/1000 gal	$1.25	$0.86	$0.84	$0.77	$0.72	$0.70

Table 4.26: Estimated Capital Costs for Alternative 4b (Two Column Treatment using Iron Media - pumping into existing on-site storage tank and repumping into system)

GFH System Facilities Costs	Capacity in MGD					
	0.03	0.1	0.2	0.5	1.0	2.0
Residuals Handling Facilities	$2,954	$7,914	$11,628	$36,545	$58,569	$66,189
Booster Pumping/ Straining	$7,500	$7,500	$8,550	$18,000	$28,000	$32,000
GFH System Facilities	$46,208	$64,027	$106,453	$199,174	$323,827	$647,655
Building	$32,000	$32,000	$32,000	$38,400	$51,840	$108,000
Piping, I&C, Electrical, Yard Piping Allowances	$22,665	$31,776	$50,653	$101,487	$164,159	$298,338
Total Facility Cost, $	$111,327	$143,217	$209,284	$393,606	$626,396	$1,152,182
Contingency, 20%	$22,265	$28,643	$41,857	$78,721	$125,279	$230,436
Taxes & Bonding, 8.5%	$11,355	$14,608	$21,347	$40,148	$63,892	$117,523
Total Estimated GFH Facility Cost	$144,948	$186,468	$272,487	$512,475	$815,567	$1,500,141

Table 4.27: Annual O&M Costs for Alternative 4b (Two Column Treatment using Iron Media - pumping into existing on-site storage tank and repumping into system)

Facility assumed to operate 100% of time	Capacity in MGD					
	0.03	0.1	0.2	0.5	1.0	2.0
Annual Power Cost, $/yr	$539	$1,617	$2,694	$2,826	$5,635	$11,253
Annual Media Replacement Costs, $/yr	$6,849	$22,831	$45,662	$114,154	$228,308	$456,615
Media Replacement Service Cost, $	$2,500	$2,500	$5,000	$8,000	$10,000	$15,000
Waste Media Disposal Costs, $/yr	$120	$264	$540	$1,320	$2,640	$5,280
Total Estimated Labor Costs, $/yr	$2,059	$2,059	$4,493	$8,299	$8,299	$8,299
Equipment Maintenance Costs, $/yr	$1,449	$1,865	$2,725	$5,125	$8,156	$15,001
Arsenic Analysis cost, $/yr	$60	$60	$60	$60	$60	$60
Total Estimated Annual O&M Costs, $/yr	$13,577	$31,195	$61,174	$139,783	$263,097	$511,509
Unit Annual O&M Costs, $/1000 gal	$1.24	$0.85	$0.84	$0.77	$0.72	$0.70

Figure 4.23: Total Capital Costs for GFH (Alternative 4a)

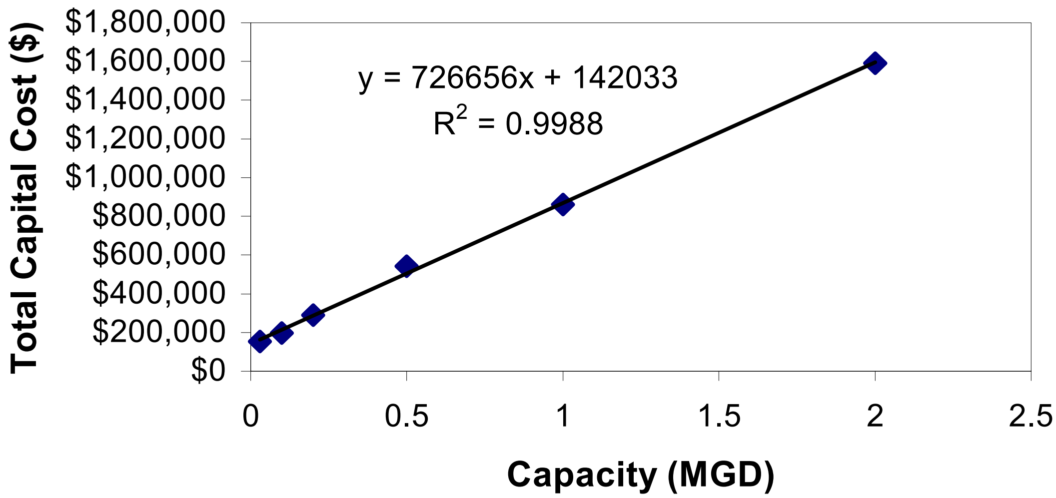


Figure 4.24: Total Annual O&M Costs for GFH (Alternative 4a)

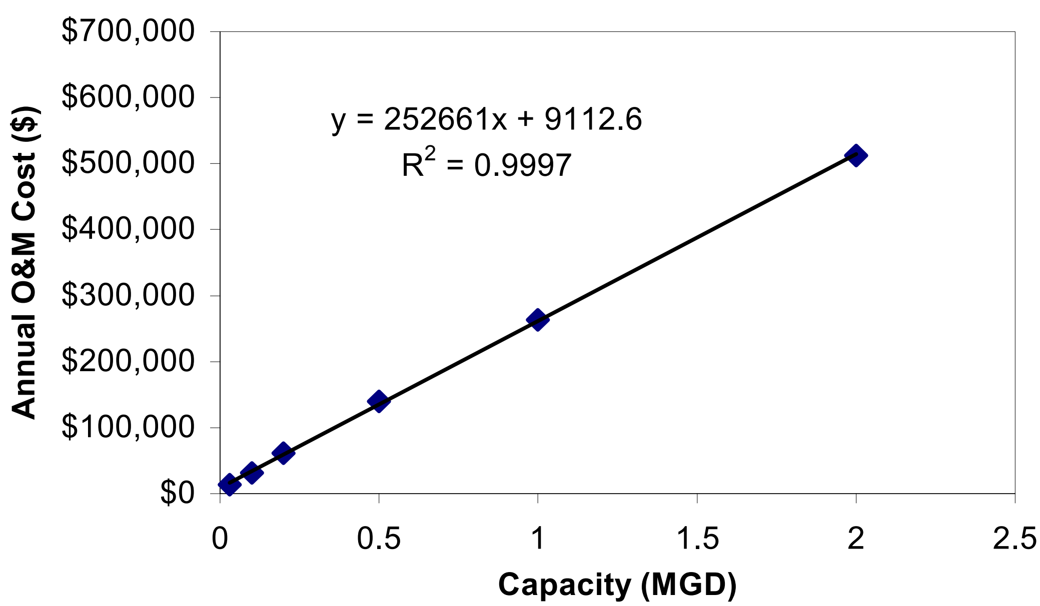


Figure 4.25: Total Capital Costs for GFH (Alternative 4b)

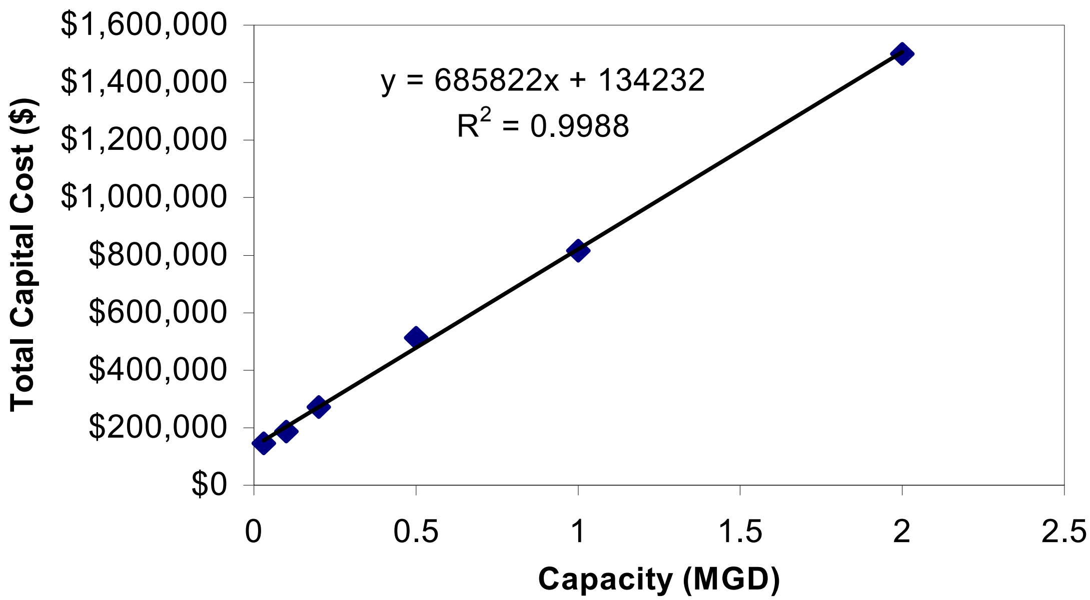
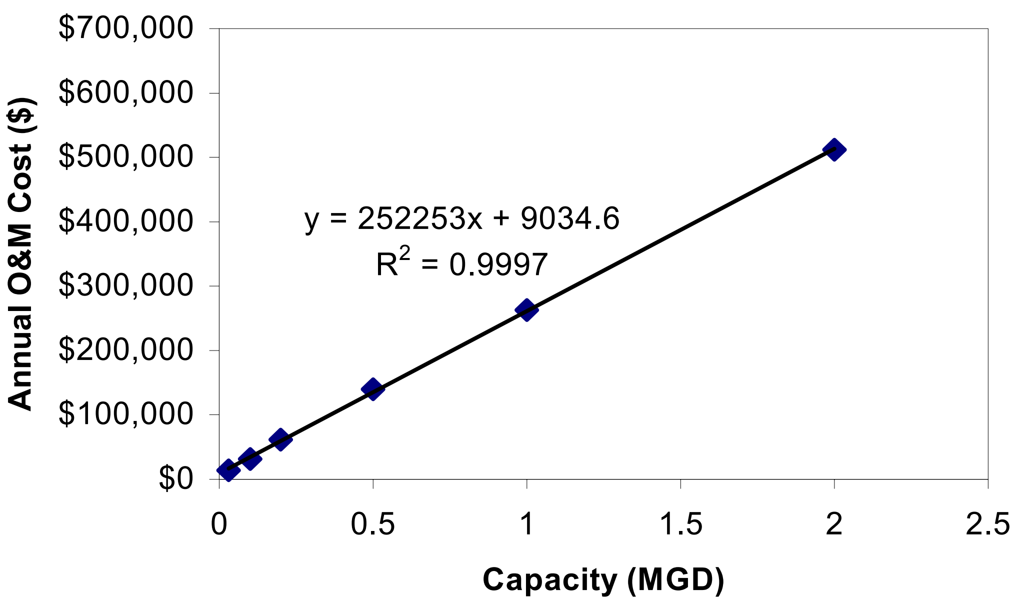


Figure 4.26: Total Annual O&M Costs for GFH (Alternative 4b)



4.4.6 Alternatives 4c and 4d Cost Models

4.4.6.1 System Design Criteria

The schematics for Alternatives 4c and 4d are shown in Figures 4.17 and 4.18, respectively. These alternatives are for systems with arsenic concentrations <20 ppb using partial stream treatment. The only difference between the two options is that under Alternative 4c, an existing storage tank is present, while under Alternative 4d, a new clearwell and booster station are constructed after treatment. The design flow through the treatment unit is 21-1389 gpm and two 2.5 minute EBCT contactors is the recommended treatment configuration. The granular iron media column was assumed to operate 100% of the time for computing O&M costs. The vessel diameter is 2-12 ft, based on the system flow. The media depth in the column is 2.7 ft. The pressure drop through the system is 20 psi. The average operating pressure is 50 psi. No pH adjustment is required. Under these operating conditions, the granular iron media column is expected to last a period of 160 days before breakthrough for a raw water with 15 ppb influent arsenic and no significant interferences. After the first column breaks through, the media is replaced and the flow is rerouted so that the raw water flows to the second column first. The granular iron media is backwashed monthly and the backwash volume is approximately 13 BVs. A steel tank is used for backwash recovery. For large systems, the spent media is stored on-site in holding area and disposed to a municipal landfill as it is not considered hazardous. Approximately 50-3,400 cubic feet of media (2,250-153,000 lbs) will have to be disposed of every year, based on the system capacity. The system design criteria for two column granular iron media treatment is shown in Table 4.28.

4.4.6.2 Cost Evaluation

A summary of estimated capital costs and annual O&M costs for Alternatives 4c and 4d are shown in Tables 4.29 and 4.30, respectively. A summary of estimated capital costs and annual O&M costs for Alternatives 4d are shown in Tables 4.31 and 4.32, respectively These estimated costs were plotted as a function of system design flow to develop capital and O&M cost curves to estimate costs for systems of various capacities throughout Arizona. The capital and O&M cost curves for Alternatives 4c are shown in Figures 4.27 and 4.28, respectively. The capital and O&M cost curves for Alternative 4d are shown in Figures 4.29 and 4.30, respectively.

Table 4.28: Design Criteria for Two column Granular Iron Media Treatment (4c and 4d)

Parameter	Units	Value
Flow	gpm	21-1389
Average Arsenic Level	ppb	15
No. of Treatment Vessels		2
Vessel Configuration		series
EBCT (each vessel)	min	2.5
Vessel Diameter	ft	2-12
Media Depth	ft	2.7
Vessel Height (side shell)	ft	6
Operating Pressure	psi	50
Maximum Headloss	psi	10-20
Maximum Operating pH	std. units	8.0
Operating time until arsenic breakthrough[1]	days	160
Acid/Caustic facilities required?		No[2]
Backwash Equalization Basin	BVs	13
Spent Media Disposal		Landfill
Backwash Frequency		Monthly
Clearwell Detention Time	min	10

[1]Media replacement interval based on continuous operation

[2]pH adjustment not necessary for granular iron media for waters up to pH 8.0

Table 4.29: Estimated Capital Costs for Alternative 4c (Two Column Partial Stream Treatment using Iron media - pumping into existing on-site storage tank and repumping into system)

GFH System Facilities Costs	Capacity in MGD					
	0.03	0.1	0.2	0.5	1.0	2.0
Residuals Handling Facilities	$2,954	$7,914	$11,628	$36,545	$58,569	$66,189
Booster Pumping/ Straining	$7,500	$7,500	$8,550	$18,000	$28,000	$32,000
Fe-AA System Facilities	$54,848	$74,827	$123,733	$225,094	$362,707	$725,415
Building	$32,000	$32,000	$32,000	$38,400	$51,840	$108,000
Piping, I&C, Electrical, Yard Piping Allowances	$26,121	$36,096	$57,565	$111,855	$179,711	$329,442
Total Facility Cost, $	$123,423	$158,337	$233,476	$429,894	$680,828	$1,261,046
Contingency, 20%	$24,685	$31,667	$46,695	$85,979	$136,166	$252,209
Taxes & Bonding, 8.5%	$12,589	$16,150	$23,815	$43,849	$69,444	$128,627
Total Estimated GFH Facility Cost	$160,697	$206,155	$303,985	$559,722	$886,437	$1,641,882

Table 4.30: Annual O&M Costs for Alternative 4c (Two Column Partial Stream Treatment using Iron media - pumping into existing on-site storage tank and repumping into system)

Facility assumed to operate 100% of time	Capacity in MGD					
	0.03	0.1	0.2	0.5	1.0	2.0
Annual Power Cost, $/yr	$539	$1,617	$2,694	$2,826	$5,635	$11,253
Annual Media Replacement Costs, $/yr	$4,566	$15,221	$30,441	$76,103	$152,205	$304,410
Media Replacement Service Cost, $	$2,500	$2,500	$5,000	$8,000	$10,000	$15,000
Waste Media Disposal Costs, $/yr	$120	$264	$540	$1,320	$2,640	$5,280
Total Estimated Labor Costs, $/yr	$2,059	$2,059	$4,493	$8,299	$8,299	$8,299
Equipment Maintenance Costs, $/yr	$1,607	$2,062	$3,040	$5,597	$8,864	$16,419
Arsenic Analysis cost, $/yr	$60	$60	$60	$60	$60	$60
Total Estimated Annual O&M Costs, $/yr	$11,451	$23,782	$46,268	$102,205	$187,703	$360,721
Unit Annual O&M Costs, $/1000 gal	$1.05	$0.65	$0.63	$0.56	$0.51	$0.49

Table 4.31: Estimated Capital Costs for Alternative 4d (Two Column Partial Stream Treatment using Iron media - pumping into new storage tank and repumping into system)

GFH System Facilities Costs	Capacity in MGD					
	0.03	0.1	0.2	0.5	1.0	2.0
Residuals Handling Facilities	$2,954	$7,914	$11,628	$36,545	$58,569	$66,189
Booster Pumping/ Straining	$61,860	$83,100	$106,950	$154,800	$202,000	$272,000
GFH System Facilities	$54,848	$74,827	$123,733	$225,094	$333,547	$783,735
Building	$32,000	$32,000	$32,000	$38,400	$51,840	$108,000
Piping, I&C, Electrical, Yard Piping Allowances	$47,865	$66,336	$96,925	$166,575	$237,647	$448,770
Total Facility Cost, $	$199,527	$264,177	$371,236	$621,414	$883,604	$1,678,694
Contingency, 20%	$39,905	$52,835	$74,247	$124,283	$176,721	$335,739
Taxes & Bonding, 8.5%	$20,352	$26,946	$37,866	$63,384	$90,128	$171,227
Total Estimated GFH Facility Cost	$259,784	$343,958	$483,349	$809,081	$1,150,452	$2,185,659

Table 4.32: Annual O&M Costs for Alternative 4d (Two Column Partial Stream Treatment using Iron media - pumping into new storage tank and repumping into system)

Facility assumed to operate 100% of time	Capacity in MGD					
	0.03	0.1	0.2	0.5	1.0	2.0
Annual Power Cost, $/yr	$539	$1,617	$2,694	$2,826	$5,635	$11,253
Annual Media Replacement Costs, $/yr	$4,566	$15,221	$30,441	$76,103	$152,205	$304,410
Media Replacement Service Cost, $	$2,500	$2,500	$5,000	$8,000	$10,000	$15,000
Waste Media Disposal Costs, $/yr	$120	$264	$540	$1,320	$2,640	$5,280
Total Estimated Labor Costs, $/yr	$2,059	$2,059	$4,493	$8,299	$8,299	$8,299
Equipment Maintenance Costs, $/yr	$2,598	$3,440	$4,833	$8,091	$11,505	$21,857
Arsenic Analysis cost, $/yr	$60	$60	$60	$60	$60	$60
Total Estimated Annual O&M Costs, $/yr	$12,442	$25,160	$48,062	$104,698	$190,344	$366,159
Unit Annual O&M Costs, $/1000 gal	$1.14	$0.69	$0.66	$0.57	$0.52	$0.50

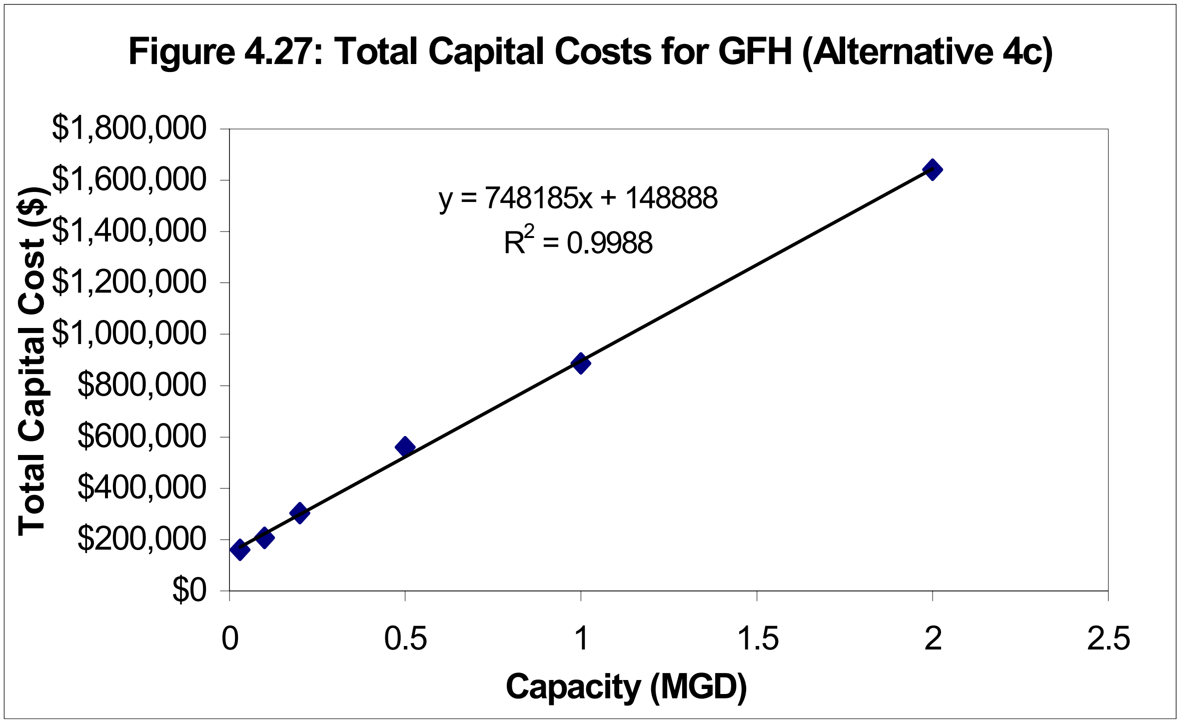


Figure 4.27: Total Capital Costs for GFH (Alternative 4c)
y = 748185x + 148888
R2 = 0.9988
Total Capital Cost ($)
$1,800,000
$1,600,000
$1,400,000
$1,200,000
$1,000,000
$800,000
$600,000
$400,000
$200,000
$0
0
0.5
1
1.5
2
2.5
Capacity (MGD)

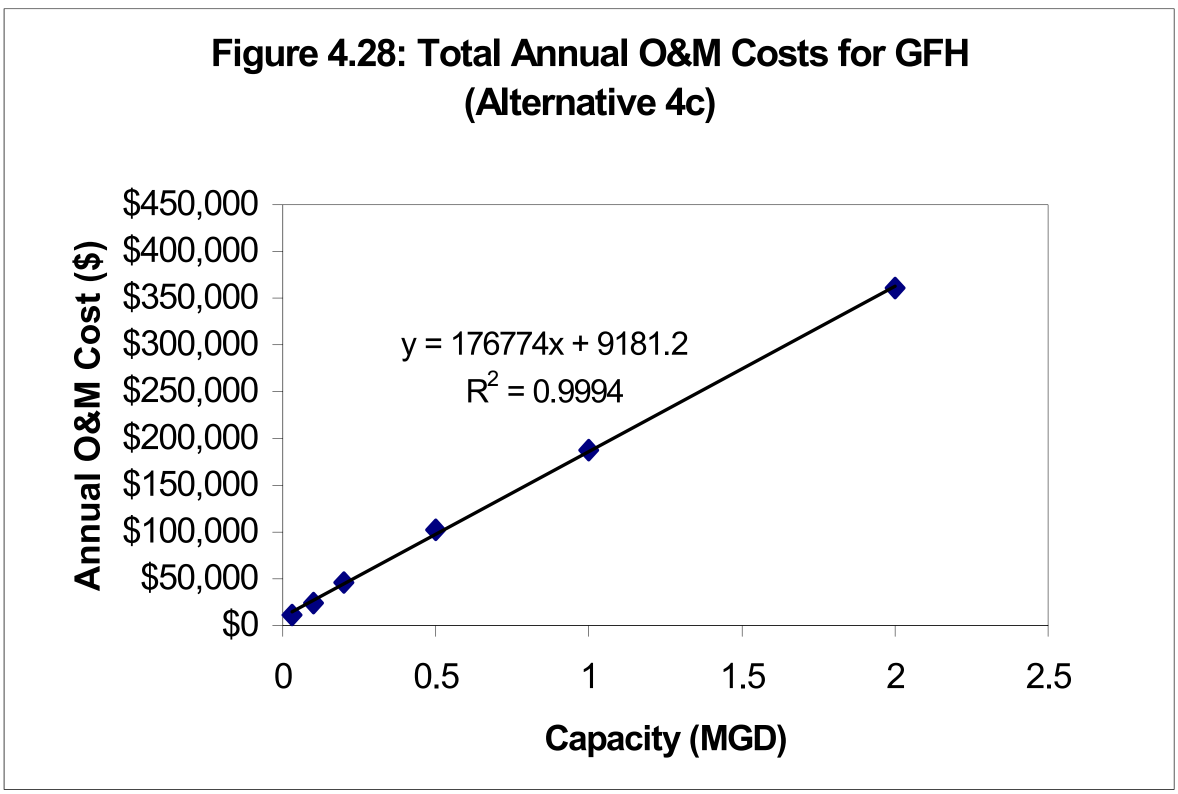


Figure 4.28: Total Annual O&M Costs for GFH (Alternative 4c)
y = 176774x + 9181.2
R2 = 0.9994
Annual O&M Cost ($)
$450,000
$400,000
$350,000
$300,000
$250,000
$200,000
$150,000
$100,000
$50,000
$0
0
0.5
1
1.5
2
2.5
Capacity (MGD)

Figure 4.29: Total Capital Costs for GFH (Alternative 4d)

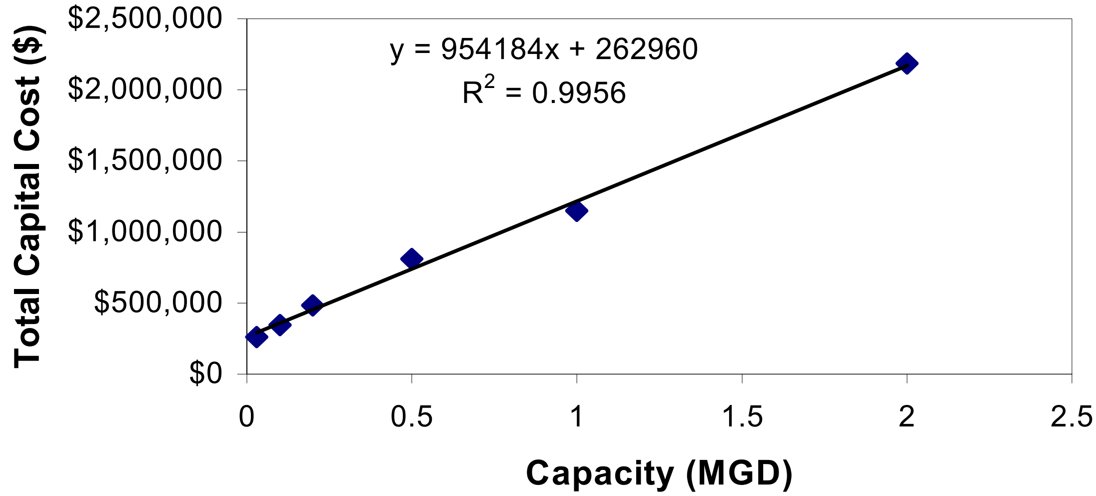
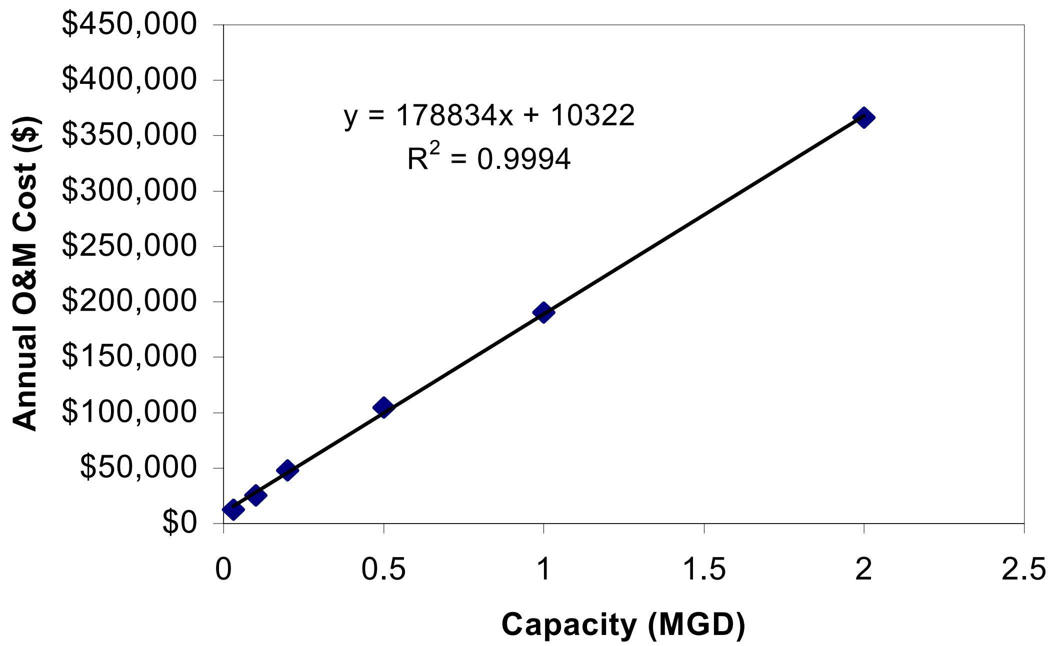


Figure 4.30: Total Annual O&M Costs for GFH (Alternative 4d)



4.4.7 Alternatives 5a and 5b Cost Models

4.4.7.1 System Design Criteria

The schematic for CF treatment is shown in Figure 4.31. These alternatives are for systems with arsenic concentrations >20 ppb and using full flow treatment. The only difference between the two options is that under Alternative 5a, the water is pumped directly into the system ,while in Alternative 5b, an existing storage tank is present. The design flow through the treatment unit is 695-3472 gpm. The CF unit was assumed to operate 100% of the time for computing O&M costs. The diameter of each pressure filtration vessel is 9-12 ft, and a minimum of two pressure filters are required. The pressure drop through the system is 20 psi and the minimum operating pressure is 30 psi. The average operating pressure is 100 psi for Alternative 5a and 30 psi for Alternative 5b. The hydraulic loading rate is 5 gpm/ft^3. Carbon steel epoxy coated pressure vessels and DIP piping are used. A 'G' value of 1000 sec^{-1} is required for providing mixing energy. A coagulant dose of 5 mg/L $FeCl_3$ is needed to treat up to 50 ppb arsenic. The thickened sludge is disposed off-site (non-hazardous waste). A steel tank is used for backwash recovery. Approximately 4,470-22,400 cubic feet of sludge (201,000-1,005,000 lbs) will have to be disposed of every year, based on the system capacity. The system design criteria for CF treatment is shown in Table 4.33.

Table 4.33: System Design Criteria for CF Treatment (5a and 5b)

Parameter	Units	Value
Flow	gpm	695-3975
Average Influent Arsenic level	ppb	20
Vessel Diameter	ft	9-12
Operating Pressure	psi	100 (Alternative 5a) 30 (Alternative 5b)
Maximum Headloss	psi	20
Maximum Operating pH	std. units	8.0
Mixing Criteria	sec^{-1}	G = 1000
Coagulant Dose (ferric chloride)	mg/L	5
Thickened Sludge Disposal		Off-site
Backwash Frequency		Monthly

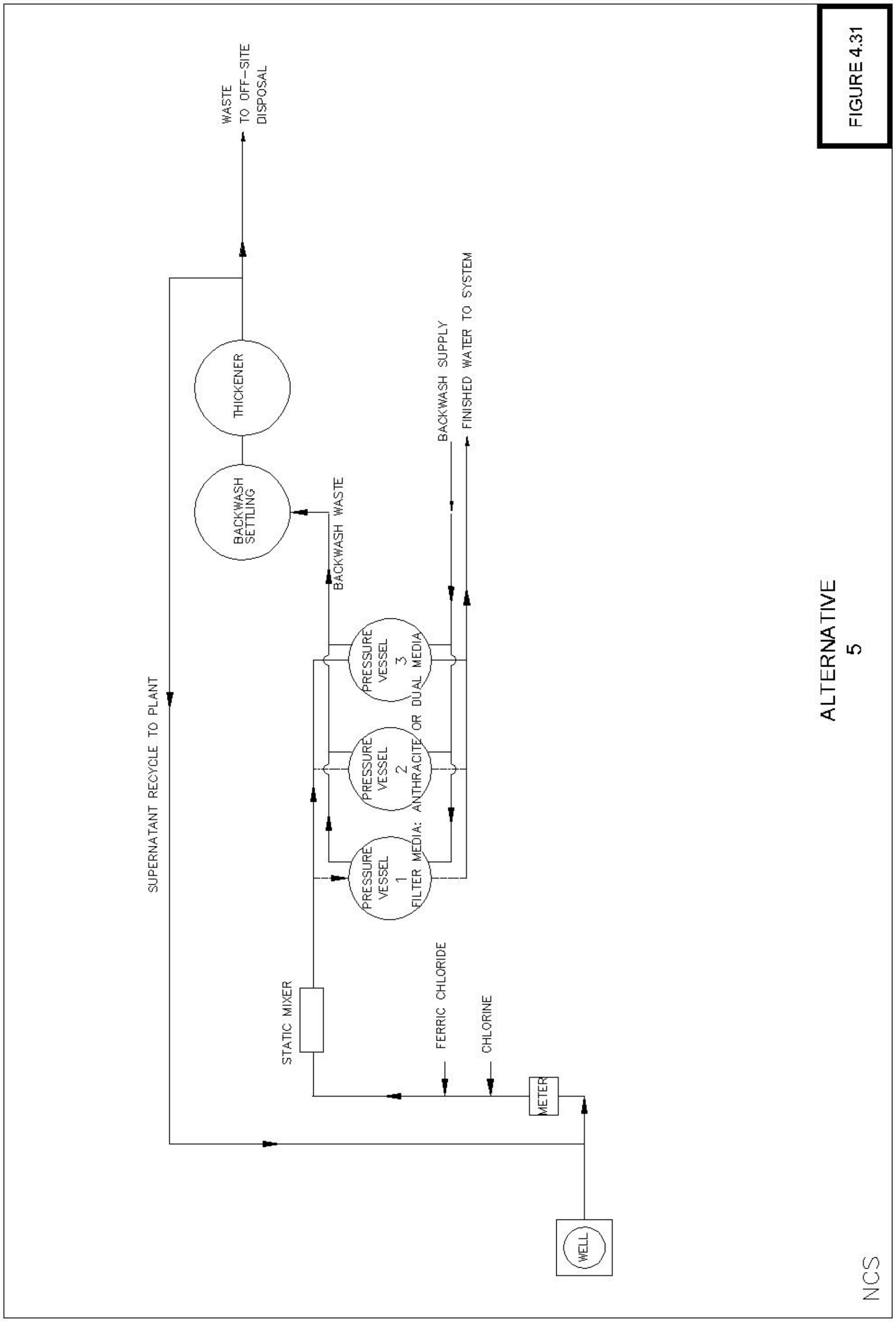


FIGURE 4.31
WASTE TO OFF-SITE DISPOSAL
SUPERNATANT RECYCLE TO PLANT
THICKENER
BACKWASH SETTLING
BACKWASH WASTE
BACKWASH SUPPLY
FINISHED WATER TO SYSTEM
PRESSURE VESSEL 1
PRESSURE VESSEL 2
PRESSURE VESSEL 3
FILTER MEDIA: ANTHRACITE OR DUAL MEDIA
STATIC MIXER
FERRIC CHLORIDE
CHLORINE
METER
WELL
ALTERNATIVE 5
NCS

4.4.7.2 Cost Evaluation

A summary of estimated capital costs and annual O&M costs for Alternative 5a are shown in Tables 4.34 and 4.35, respectively. A summary of estimated capital costs and annual O&M costs for Alternative 5b are shown in Tables 4.36 and 4.37, respectively. These estimated costs were plotted as a function of system design flow to develop capital and O&M cost curves to estimate costs for systems of various capacities throughout Arizona. The capital and O&M cost curves for Alternative 5a are as shown in Figures 4.32 and 4.33 respectively. The capital and O&M cost curves for Alternative 5b are as shown in Figures 4.34 and 4.35, respectively.

Table 4.34: Estimated Capital Costs for Alternative 5a (CF Treatment - direct pumping into system)

Capital Cost Summary	Capacity in MGD					
	1	1.5	2.0	3.0	4.0	5.0
Booster Pumping/ Straining	$18,000	$19,200	$24,000	$42,000	$48,000	$84,000
Rapid Mixing	$18,000	$21,600	$24,000	$27,600	$30,000	$33,600
Pressure Filters	$360,000	$450,000	$480,000	$720,000	$900,000	$1,080,000
Chemical Feed Systems	$11,700	$16,900	$21,500	$28,600	$34,500	$39,000
Building	$51,840	$77,440	$96,000	$134,400	$144,000	$192,000
Piping, I&C, Electrical, Yard Piping Allowances	$142,700	$177,700	$192,300	$286,400	$354,400	$432,800
Total Facility Cost, $	$602,240	$762,840	$837,800	$1,239,000	$1,510,900	$1,861,400
Contingency, 20%	$120,400	$152,600	$167,600	$247,800	$302,200	$372,300
Taxing & Bonding, 8.5%	$61,400	$77,800	$85,500	$126,400	$154,100	$189,900
Total Estimated CF Facility Cost, WO Residuals	$784,000	$993,200	$1,090,900	$1,613,200	$1,967,200	$2,423,600
Solids Handling	$160,800	$144,900	$217,800	$288,300	$360,900	$418,200
Piping, I&C, Electrical, Yard Piping Allowances	$56,300	$50,700	$76,200	$100,900	$126,300	$146,400
Contingency, 20%	$43,400	$39,100	$58,800	$77,800	$97,400	$112,900
Taxing & Bonding, 8.5%	$22,143	$19,950	$29,988	$39,695	$49,691	$57,588
Total Estimated C/MF Residuals Handling Cost	$282,600	$254,600	$382,800	$506,700	$634,300	$735,100
Total Estimated CF Costs	$1,066,600	$1,247,800	$1,473,700	$2,119,900	$2,601,500	$3,158,700

Table 4.35: Estimate Annual O&M Costs for Alternative 5a (CF treatment - direct pumping into system)

Annual O&M Costs	Capacity in MGD					
	1.0	1.5	2.0	3.0	4.0	5.0
Annual Power Cost, $/yr	$2,300	$10,000	$4,100	$6,000	$7,800	$9,700
FeCl3 Cost, $/yr	$2,900	$4,300	$5,800	$8,700	$11,600	$14,500
Residuals Disposal Costs, $/yr	$40,200	$60,300	$80,400	$120,500	$160,700	$200,900
Total Estimated Labor Costs, $/yr	$45,500	$65,500	$45,500	$65,500	$65,500	$65,500
Equipment Maintenance Costs, $/yr	$10,700	$11,500	$14,700	$21,200	$26,000	$31,600
Total Estimated Annual O&M Costs, $/yr	$101,600	$151,600	$150,500	$221,900	$271,600	$322,200
Unit Annual O&M Costs, $/1000 gal	$0.93	$0.92	$0.69	$0.68	$0.62	$0.59

Table 4.36: Estimated Capital Costs for Alternative 5b (CF Treatment - pumping into existing on-site storage tank and repumping into the system)

Capital Cost Summary	Capacity in MGD					
	1	1.5	2.0	3.0	4.0	5.0
Booster Pumping/ Straining	$18,000	$19,200	$24,000	$42,000	$48,000	$84,000
Rapid Mixing	$18,000	$21,600	$24,000	$27,600	$30,000	$33,600
Pressure Filters	$360,000	$450,000	$480,000	$720,000	$900,000	$1,080,000
Chemical Feed Systems	$11,700	$16,900	$21,500	$28,600	$34,500	$39,000
Building	$51,840	$77,440	$96,000	$134,400	$144,000	$192,000
Piping, I&C, Electrical, Yard Piping Allowances	$142,700	$177,700	$192,300	$286,400	$354,400	$432,800
Total Facility Cost, $	$602,240	$762,840	$837,800	$1,239,000	$1,510,900	$1,861,400
Contingency, 20%	$120,400	$152,600	$167,600	$247,800	$302,200	$372,300
Taxing & Bonding, 8.5%	$61,400	$77,800	$85,500	$126,400	$154,100	$189,900
Total Estimated CF Facility Cost, WO Residuals	$784,000	$993,200	$1,090,900	$1,613,200	$1,967,200	$2,423,600
Solids Handling	$160,800	$144,900	$217,800	$288,300	$360,900	$418,200
Piping, I&C, Electrical, Yard Piping Allowances	$56,300	$50,700	$76,200	$100,900	$126,300	$146,400
Contingency, 20%	$43,400	$39,100	$58,800	$77,800	$97,400	$112,900
Taxing & Bonding, 8.5%	$22,143	$19,950	$29,988	$39,695	$49,691	$57,588
Total Estimated C/MF Residuals Handling Cost	$282,600	$254,600	$382,800	$506,700	$634,300	$735,100
Total Estimated CF Costs	$1,066,600	$1,247,800	$1,473,700	$2,119,900	$2,601,500	$3,158,700

Table 4.37: Estimate Annual O&M Costs for Alternative 5b (CF treatment - pumping into existing on-site storage tank and repumping into the system)

Annual O&M Costs	Capacity in MGD					
	1.0	1.5	2.0	3.0	4.0	5.0
Annual Power Cost, $/yr	$2,300	$10,000	$4,100	$6,000	$7,800	$9,700
FeCl3 Cost, $/yr	$2,900	$4,300	$5,800	$8,700	$11,600	$14,500
Residuals Disposal Costs, $/yr	$40,200	$60,300	$80,400	$120,500	$160,700	$200,900
Total Estimated Labor Costs, $/yr	$45,500	$65,500	$45,500	$65,500	$65,500	$65,500
Equipment Maintenance Costs, $/yr	$10,000	$11,500	$13,900	$19,900	$24,400	$29,700
Total Estimated Annual O&M Costs, $/yr	$100,900	$151,600	$149,700	$220,600	$270,000	$320,300
Unit Annual O&M Costs, $/1000 gal	$0.92	$0.92	$0.68	$0.67	$0.62	$0.59

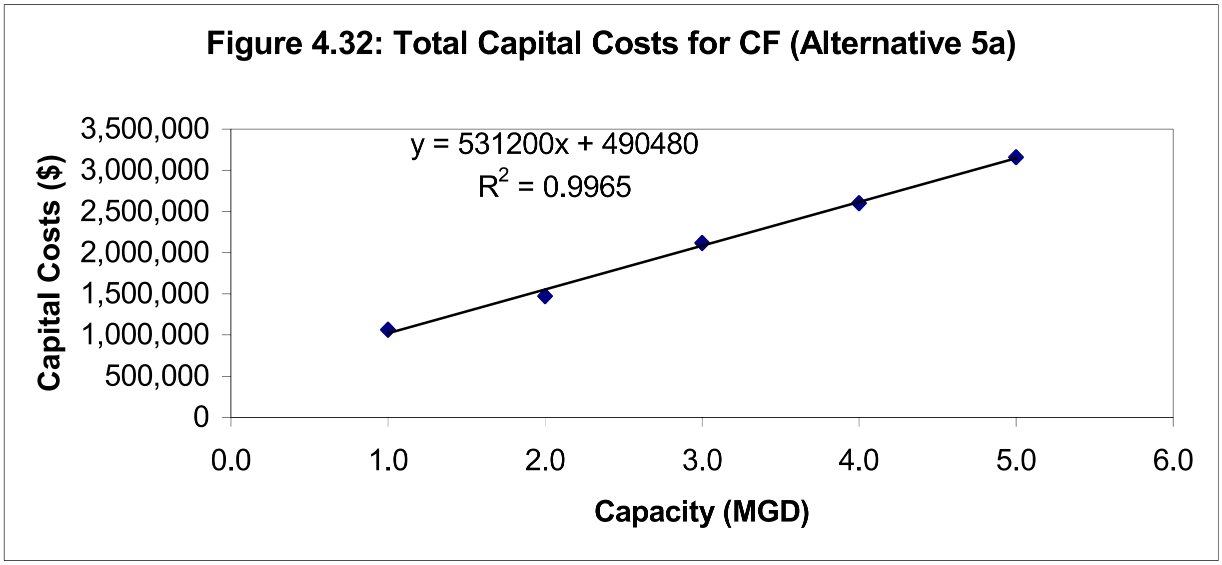


Figure 4.32: Total Capital Costs for CF (Alternative 5a)
y = 531200x + 490480
R2 = 0.9965
Capital Costs ($)
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
Capacity (MGD)

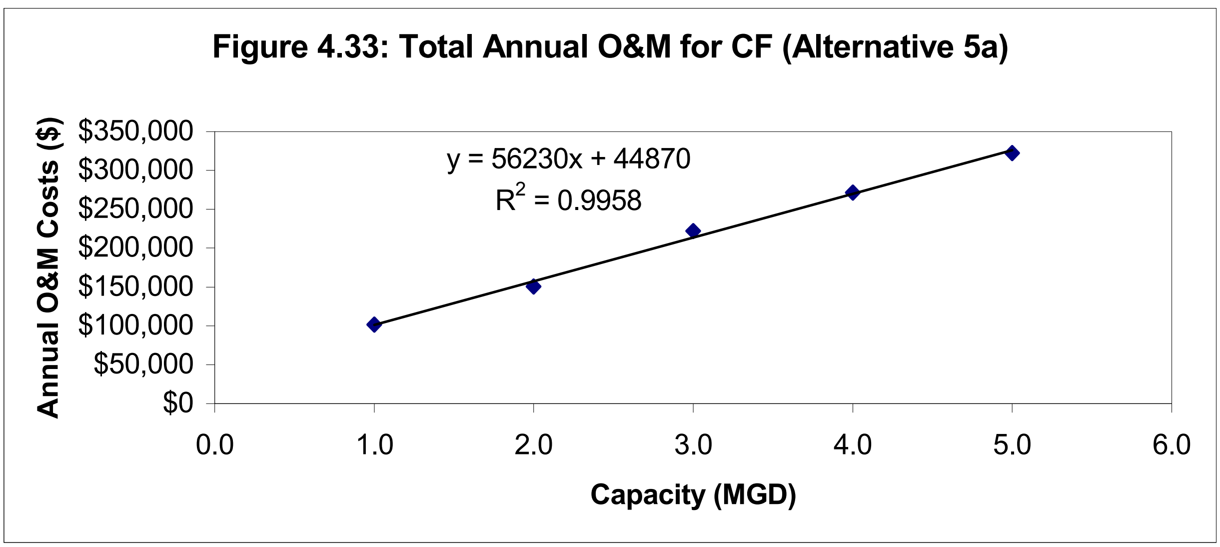


Figure 4.33: Total Annual O&M for CF (Alternative 5a)
y = 56230x + 44870
R2 = 0.9958
Annual O&M Costs ($)
$350,000
$300,000
$250,000
$200,000
$150,000
$100,000
$50,000
$0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
Capacity (MGD)

Figure 4.34: Total Capital Costs for CF (Alternative 5b)

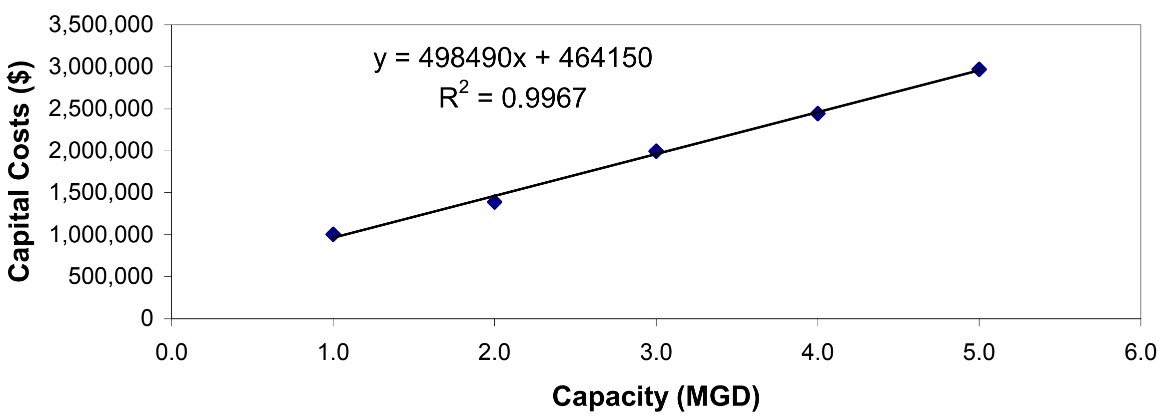
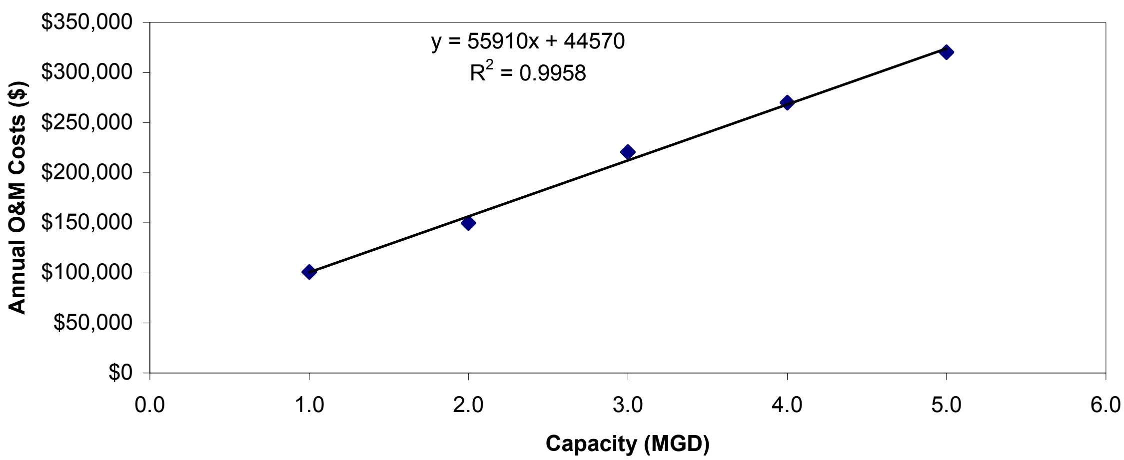


Figure 4.35: Total Annual O&M for CF (Alternative 5b)



4.4.8 Alternative 6 Cost Model

4.4.8.1 Cost Evaluation

Capital and O&M costs for POU adsorption units and POU reverse osmosis (RO) units were developed based on the assumptions discussed in Section 4.3.3. A comparison of centralized treatment and POU device treatment for small systems was performed to determine whether POU treatment devices are cost-effective for small systems. A discussion of these costs and the results of the comparison is provided below.

The estimated capital and annual O&M costs for POU RO and POU adsorption were calculated based on the assumptions mentioned in Section 4.3.3. One arsenic sample was assumed to be collected from each household every year and operator labor charges were assumed at 8 hours/year and managerial charges at 2 hours/year. Capital and O&M costs were calculated for the total number of households served and annualized costs were developed. A summary of the capital, O&M and annualized treatment costs for centralized treatment and POU units is shown in Table 4.38. Examples of cost calculations for POU RO treatment and POU AA treatment are shown below assuming that the units serve 20 households.

4.4.8.2 POU Reverse Osmosis Costs

Capital Cost	=	(media cost + installation cost) x total number of households
	=	($350 + $150) x 20
	=	$10,000.
Annual O&M Cost	=	(media replacement cost + labor charges @ 8hrs/year + management charges @ 2 hrs/year + sample analysis cost) x total number of households
	=	($95 + $25 x 8 + $50 x 2 + $12) x 20
	=	$8,140.
Annualized Cost	=	Capital Cost/11.47 + O&M Cost
	=	$10,000/11.47 + $8,140
	=	$9,012

where 11.47 is the present worth factor on 6% annual interest rate.

4.4.8.3 POU Adsorption Costs

Capital Cost	=	(media cost + installation cost) x total number of households
	=	($150 + $150) x 20
	=	$6,000.
Annual O&M Cost	=	(media replacement cost + labor charges @ 8hrs/year + management charges @ 2 hrs/year + sample analysis cost) x total number of households

	=	($70 + $25 x 8 + $50 x 2 + $12) x 20
	=	$7,640.
Annualized Cost	=	Capital Cost/11.47 + O&M Cost
	=	$6,000/11.47 + $7,640
	=	$8,163.

where 11.47 is the present worth factor on 6% annual interest rate.

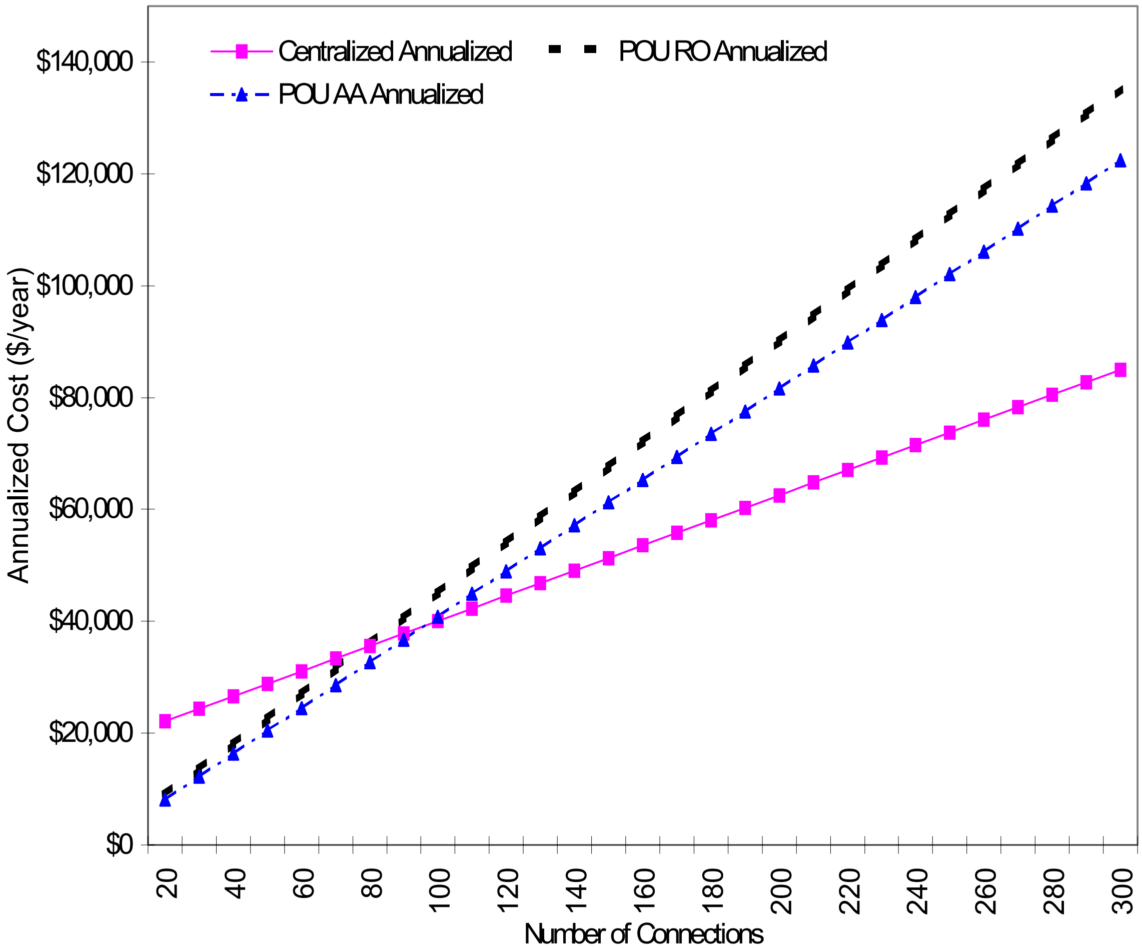
A comparison between centralized treatment costs using the capital and O&M costs determined for Alternative 1 and POU treatment costs is as shown in Figure 4.36. It was observed that the POU RO and the POU AA costs were significantly lower than centralized treatment costs for systems serving fewer than 30 connections. For these systems, POU RO annualized costs were $13,518, POU AA annualized costs were $12,245 and central treatment annualized costs were $26,580 (Alternative 1a). As the number of connections increased, the POU costs also increased gradually and the breakpoint cost was observed at 80 connections for the POU RO and at 90 connections for the POU AA. The cost per month per household was $37 for the POU RO and $34 for the POU AA, both of which were less than centralized treatment cost per month per household until 80 and 90 connections respectively. It was observed that the annual O&M costs for the POU units were higher than for central treatment, for systems serving greater than 50 connections. These higher annual O&M costs can be attributed to an increase in administrative, monitoring and cartridge replacement costs. The capital costs of the POU units, however, were consistently lower than central treatment capital costs. From an overall cost evaluation, POU treatment is cost-effective when compared to centralized treatment and may be viable for very small systems.

POU units always have significantly lower capital costs, ranging from 5 to 20 percent of central treatment costs, for systems with 20 to 300 connections, respectively. This suggests that the substantial capital cost savings may lead very small utilities towards POU treatment for arsenic.

4.4.8.4 POU Cost Evaluation from AwwaRF Survey

Based on a manufacturers survey conducted for Awwa Research Foundation Project, “Point-of-Use Implementation Feasibility Study for Arsenic Removal”, it was concluded that water systems can either purchase the POU units or lease them from a vendor. Based on vendor quotes, POU costs for the purchase and the lease options are presented below. Utilities can select the option that best suits their needs based on issues related to public perception, maintenance of the POU units, compliance monitoring etc.

Figure 4.36: Break Point Costs for Centralized Treatment vs. POU Treatment



Lease vs Purchase Option- The comparison of lease vs purchase option costs is presented below. Types of POU units:

POU RO Annualized Cost	=	($350 + $150)/11.47 + ($95 x 1.25 + $12)
(Purchase)	=	$174
	=	$15/month.
POU Adsorption Annualized Cost	=	($150 + $150)/11.47 + ($70 x 1.25 + $12)
(Purchase)	=	$126
	=	$11/month

The total annualized POU costs were calculated taking into consideration a present worth factor of 11.47 on a 6% annual interest rate and an additional 25% charges for maintenance of the units (e.g., unscheduled service cost, on-call service items, customer inquiries). Annualized costs for POU RO and POU adsorption were $174 and $126, respectively, and the monthly cost per household was $15 for POU RO and $11 for POU adsorption.

Based on vendor quotes, the costs for leasing the POU units were $20-$25/month for the POU RO and $15 for the POU adsorption units. These costs were similar to the lease costs for adsorption, and due to compliance and logistics, the lease option was used in the model.

4.5 SUMMARY

A comparison of capital, O&M, and annualized costs of all the treatment options to be considered in the AMP is presented in Tables 4.39, 4.40 and 4.41, respectively. These cost models were used to perform the state-wide arsenic evaluation discussed in Section 5. There is a wide range of costs between the options and these alternatives should not be compared against each other because the application of each alternative is dependent on site-specific conditions. For example, partial stream treatment will significantly reduce the treatment plant size, and when comparing alternatives for a particular site, the WTP size is different for the various alternatives (full treatment vs. partial treatment).

Table 4.39: Comparison of Capital Costs

	Treatment Plant Capacity in MGD					
Alternatives	0.03	0.1	0.2	0.5	1.0	2.0
1a	$ 126,100	$ 185,300	$ 239,100	$ 485,500	$ 752,700	$ 1,350,800
1b	$ 121,700	$ 177,600	$ 230,400	$ 466,600	$ 727,600	$ 1,300,500
2a	$ 107,200	$ 133,600	$ 184,200	$ 346,000	$ 543,100	$ 955,100
2b	$ 102,800	$ 128,100	$ 175,500	$ 330,900	$ 520,400	$ 909,900
3a	$ 171,100	$ 222,400	$ 336,300	$ 569,900	$ 921,500	$ 1,939,800
3b	$ 162,400	$ 211,500	$ 318,700	$ 544,700	$ 883,700	$ 1,839,200
3c	$ 178,100	$ 231,100	$ 346,300	$ 584,100	$ 942,800	$ 1,996,600
3d	$ 276,100	$ 361,300	$ 508,700	$ 1,012,300	$ 148,100	$ 2,672,000
4a	$ 153,700	$ 197,400	$ 290,000	$ 542,700	$ 860,800	$ 1,590,700
4b	$ 144,900	$ 186,500	$ 272,500	$ 512,500	$ 815,600	$ 1,500,100
4c	$ 160,700	$ 206,200	$ 304,000	$ 559,700	$ 886,400	$ 1,641,900
4d	$ 259,800	$ 344,000	$ 483,300	$ 809,100	$ 1,150,400	$ 2,185,700
5a	n/a	n/a	n/a	n/a	$ 1,066,600	$ 1,247,800
5b	n/a	n/a	n/a	n/a	$ 1,003,400	$ 1,247,800

Table 4.40: Comparison of Annual O&M Costs

	Treatment Plant Capacity in MGD					
Alternatives	0.03	0.1	0.2	0.5	1.0	2.0
1a	$ 7,300	$ 16,900	$ 32,300	$ 72,500	$ 134,500	$ 256,200
1b	$ 7,300	$ 16,800	$ 32,200	$ 72,400	$ 134,200	$ 255,700
2a	$ 10,900	$ 23,200	$ 45,100	$ 100,800	$ 185,600	$ 353,800
2b	$ 10,900	$ 23,100	$ 45,000	$ 100,600	$ 185,400	$ 353,300
3a	$ 9,300	$ 22,200	$ 43,000	$ 97,900	$ 185,200	$ 360,100
3b	$ 9,200	$ 22,100	$ 42,900	$ 97,600	$ 184,800	$ 359,100
3c	$ 7,800	$ 17,300	$ 33,200	$ 73,400	$ 136,300	$ 262,600
3d	$ 8,800	$ 18,700	$ 35,000	$ 77,800	$ 141,800	$ 269,400
4a	$ 13,700	$ 31,300	$ 61,300	$ 140,100	$ 263,600	$ 512,400
4b	$ 13,600	$ 31,200	$ 61,200	$ 139,800	$ 263,100	$ 511,500
4c	$ 11,500	$ 23,800	$ 46,300	$ 102,200	$ 187,700	$ 360,700
4d	$ 12,400	$ 25,200	$ 48,100	$ 104,700	$ 190,300	$ 366,200
5a	n/a	n/a	n/a	n/a	$ 271,600	$ 322,200
5b	n/a	n/a	n/a	n/a	$ 270,000	$ 320,300

Table 4.41: Comparison of Annualized Costs

	Treatment Capacity in MGD					
Alternatives	0.03	0.1	0.2	0.5	1.0	2.0
1a	$ 18,294	$ 33,055	$ 53,146	$ 114,828	$ 200,123	$ 373,968
1b	$ 17,910	$ 32,284	$ 52,287	$ 113,080	$ 197,635	$ 369,083
2a	$ 20,246	$ 34,848	$ 61,159	$ 130,966	$ 232,950	$ 437,069
2b	$ 19,863	$ 34,268	$ 60,301	$ 129,449	$ 230,771	$ 432,629
3a	$ 24,217	$ 41,590	$ 72,320	$ 147,586	$ 265,540	$ 529,219
3b	$ 23,359	$ 40,539	$ 70,686	$ 145,089	$ 261,844	$ 519,449
3c	$ 23,327	$ 37,448	$ 63,392	$ 124,324	$ 218,497	$ 436,671
3d	$ 32,871	$ 50,200	$ 79,350	$ 166,056	$ 154,712	$ 502,356
4a	$ 27,100	$ 48,510	$ 86,583	$ 187,415	$ 338,648	$ 651,084
4b	$ 26,233	$ 47,460	$ 84,958	$ 184,482	$ 334,207	$ 642,285
4c	$ 25,510	$ 41,777	$ 72,804	$ 150,997	$ 264,980	$ 503,847
4d	$ 35,050	$ 55,191	$ 90,236	$ 175,241	$ 290,596	$ 556,758
5a	n/a	n/a	n/a	n/a	$ 364,590	$ 430,988
5b	n/a	n/a	n/a	n/a	$ 357,480	$ 429,088

List of Treatment Options Evaluated

1a - Fe-AA adsorption with single column and direct pumping into the distribution system
1b - Fe-AA adsorption with single column, pumping into a storage tank and re-pumping into the distribution system
2a - Granular iron media adsorption with single column and direct pumping into the distribution system

2b - Granular iron media adsorption with single column, pumping into a storage tank and re-pumping into the distribution system
3a - Fe-AA adsorption with two columns in series, full-flow is treated, direct pumping into the distribution system
3b - Fe-AA adsorption with two columns in series, full flow is treated, pumping into existing storage tank and re-pumping into the distribution system
3c - Fe-AA adsorption with two columns in series, partial stream is treated, pumping into existing storage tank and re-pumping into the distribution system
3d - Fe-AA adsorption with two columns in series, partial stream is treated, pumping into new storage tank and re-pumping into the distribution system
4a - Granular iron media adsorption with two columns in series, full flow is treated, direct pumping into the distribution system
4b - Granular iron media adsorption with two columns in series, full flow is treated, pumping into existing storage tank and re-pumping into the distribution system
4c - Granular iron media adsorption with two columns in series, partial stream is treated, pumping into existing storage tank and re-pumping into the distribution system
4d - Granular iron media adsorption with two columns in series, partial stream is treated, pumping into new storage tank and re-pumping into the distribution system
5a - Coagulation, granular media filtration, direct pumping into the system
5b - Coagulation, granular media filtration, pumping into an existing storage tank
6a - Point-of-use (POU) treatment by adsorption
6b - POU treatment by reverse osmosis